DESIGN OF A BRAILLE LINEPRINTER

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PROEFONTWERP

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1. GENERAL ASPECTS

1.1. Introduction.

Since brailled material is not required on the same scale as printed material, the amount of research that has been directed towards production methods for braille, has always remained rather small. Hence perhaps that the availability of braille material has historically always lagged behind the availability of printed matter. (This fact caused to a certain extent the relatively modest use of braille as a means of communication between visually handicapped people.)

The growing role that electronic data processing is playing in our society, has had at least two consequences in the field of the visually handicapped:

- Visually handicapped people working in a data processing environment have developed the need for a fast access possibility to data banks, in order to stay competitive with their sighted colleagues.
- The decreasing costs of computers have led to the introduction of this equipment into braille production, specially in the first stage of the production process: the translation from inkprint to braille.
  In order to exploit this possible increase in input speed of the braille production chain effectively, another link needed attention: the brailling devices that were used at the end of the chain. Both speed and reliability of these devices were not matched with the same properties at the input side.

The solution to both problems is already existing in the "printed matter" environment and their "braille" equivalents would be called:

- a computer terminal with hard copy braille output;
- a braille lineprinter.

The project about which this thesis reports was an attempt to develop a device that could be used to serve the above mentioned two functions.

It was started in 1973 at the Laboratory for Fine Mechanics of the Delft University of Technology as a result of contacts with the "Nederlandse Blindenbibliotheek" at The Hague.

1.2. The braille system.

The braille system was introduced in 1825 by the Frenchman Louis Braille as a means of recording texts for visually handicapped people. The system consists of 64 different codes, where each code is made up of a maximum of six dots which are positioned in two columns of three dots. These dots are

made on paper by deforming the paper with small pins at those positions where dots are wanted. In this way the surface of the paper is raised a little bit above the level of the rest of the paper; when the reader touches the surface of the paper with his (or her) fingertips, the braille dots present a tactile image. One advantage of this system is, that it offers both read and write capability to the user. A survey of the possible braille codes and their meaning is given in Appendix 8.5.
In uncontracted braille each matrix of six dotpositions represents one character (with a few exceptions). Such a matrix is called a braillecell. In order to decrease the volume necessary to represent a given text a system of contractions was introduced, in which one braillecell can represent a group of characters, the so-called "grade two" braille. Frequently used combinations of characters in a certain language can now be represented by one braillecell. This reduction in the number of braille-cells which are necessary to represent a given printed text can amount up to 30% for a "grade three" contraction system for the Dutch language (ref.1).
To get an impression about the amount of text on a sheet of braillepaper, compared to a printed text, the following numbers are given: on a sheet of braillepaper of the size used in the Netherlands about 30 braillelines can appear, each containing about 35 braillecells. These numbers can be compared with a normal printed sheet of paper, containing 45 lines of about 60 characterpositions. In uncontracted braille, this means a sheet of braille can contain only about 40% of the information which is on a printed sheet of paper of about size A4.
This difference even increases when we introduce the weight and the size of the used paper in the comparison. When several sheets of paper, containing braille, are piled up, the weight of the paper tends to reduce the height of the brailledots, making them difficult to read. Another phenomenon which is different from printed text, is the physical contact between the text and the readers fingertips during reading. This causes a certain amount of wear each time a braille text is read, resulting in a slight reduction of the height of the brailledots. So in order to produce lasting braille, the paper which is used for braille books is normally of a heavier grade than that used for printed books. A typical value in the Netherlands is paper with a weight of 160 grams per square meter for braille compared to 100 grams per square meter for printed books. So the braille version of a popular small pocket-size dictionary of the Dutch language weighs 100 times as much as the printed version and takes about 175 times its physical volume (ref.2). This explains the introduction of a contracted braille

system.

Because the use of the braille system is limited to visually handicapped people and only a part of them is actively using braille, the braille market is small, and so is the number of producers of brailling equipment. Up till now this has caused a lack of normalization in the dimensions of braillecells and the brailledots which make up these cells. Fortunately however, for a designer of braille producing equipment, the size of brailledots and -cells has to be adapted to the size of the fingertip of the human reader and his ability to discriminate different brailledots from each other. This fact has apparently caused some unity in the size of braillecells. For instance the handbrailler made by "Perkins", a large manufacturer in the U.S.A., produces braille with a distance between the dots in one braillecell of 2.2 mm, a braillecell pitch of 6.13 mm and a line distance of 10.0 mm. A similar brailler produced by "Blista" (W-Germany) features the following dimensions: 2.5 mm between the dots of one braillecell, 6.1 mm cell pitch and 10.8 mm line distance.

A closer examination of the brailledots shows the large variation in form of the dots when one makes a cross-section through the centerline of a dot. This can be done by dipping a piece of brailled material in a polyester resin, allowing the resin to harden and then making a cut perpendicular to the papersurface.
If the diameter of a brailledot is defined as the diameter which can be measured at a height which is half of the maximum height of the dot, the following observations can be made:
The "Perkins" brailler produces dots with diameters between 0.8 and 1.2 mm and with maximum height between 0.15 and 0.42 mm. For a "Blista" brailler the diameter can vary between 1.0 and 1.5 mm with heights from 0.24 till 0.36 mm. These measurements were taken after reading the braille texts a few times (ref.3). This brings us to another important point concerning braille, which is the definition of braille quality. From these investigations (some photographs are added here in Fig. 1), it is obvious that it is difficult to characterize the form of a brailledot completely with a few well chosen parameters.
However the main aspects of braille quality are related with only two variables: the height of the produced brailledot and its position on the paper. Inaccuracies in these two quantities have the greatest impact on the readability of the brailled text. So good quality braille consists of

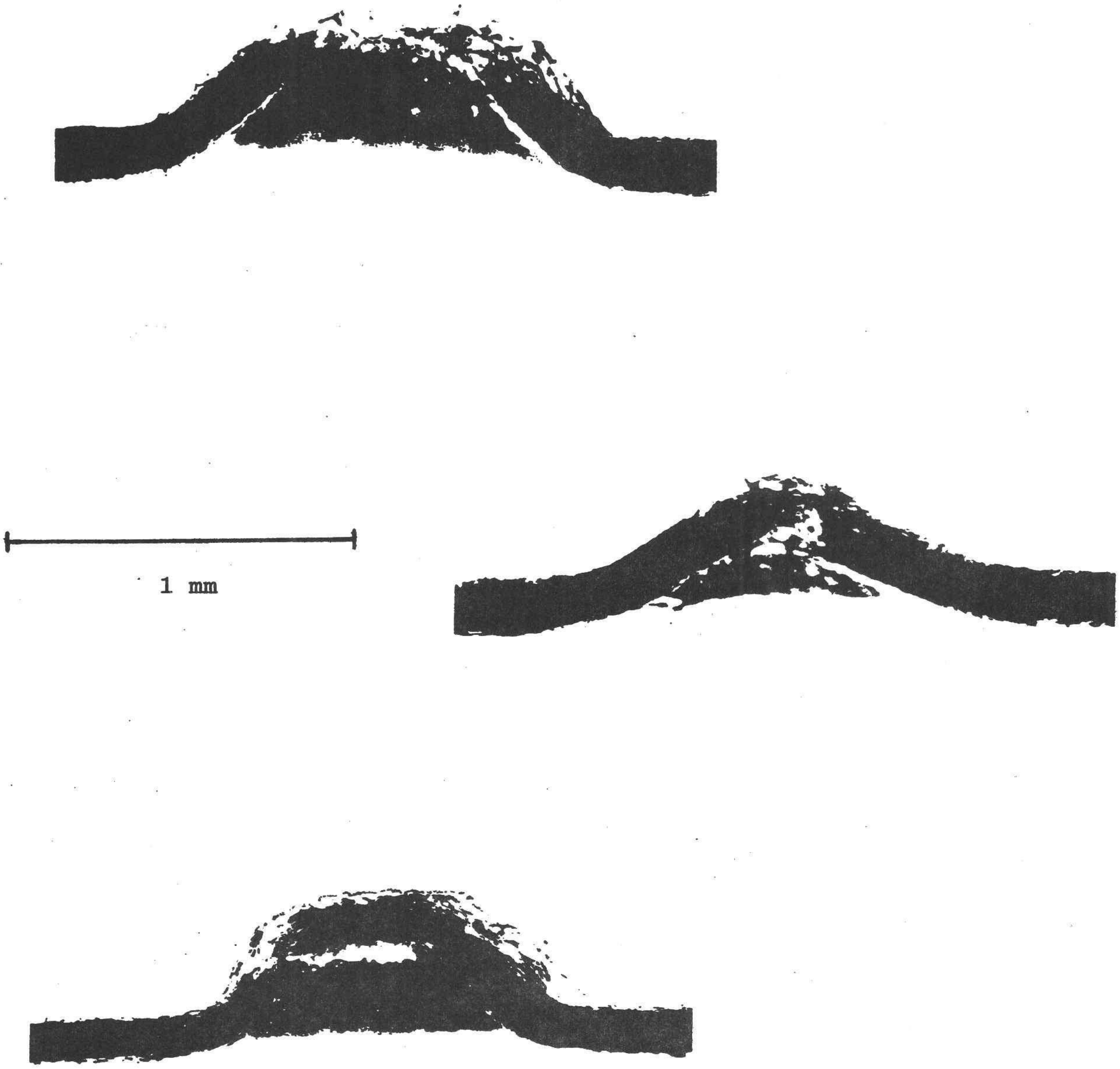

FIGURE 1

Cross-section through three different brailledots.

brailledots of constant height and with constant distances between these dots (dot-pitch).

1.3. Braille embossing processes.

The introduction of a definition of braille quality automaticly leads to the question how this braille quality can be influenced. It is obvious that one important point influencing the quality is the production process that is used. Therefore a short survey of some braille production techniques is given here.

1.3.1 Brailling equipment.

For the largest numbers of copies to be made from a single text (above 30 copies), a process is used that employs zinc plates. A zinc plate of twice the size of the braille page to be made, is folded in half and the pattern to be embossed eventually in the braille paper is embossed in both halves of the zinc plate at the same time. This is done by forcing steel pins with rounded ends into the zinc plates, which are placed on dies with corresponding spherical holes in them.

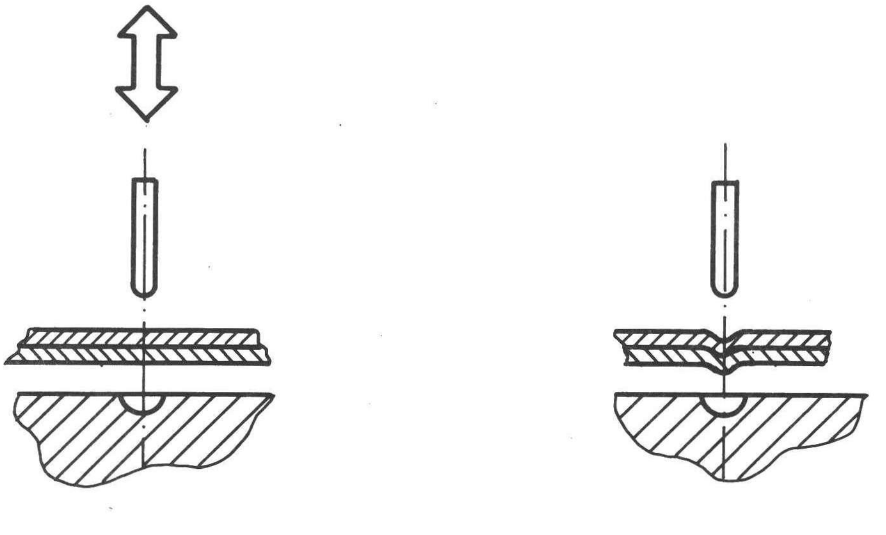

FIGURE 2
The embossing of zinc plates.

When the complete page is embossed in this way (this takes 1.6 minutes on the latest machine for this work) these two halves of the zinc plate are

separated and mounted on a regular book printing machine. Before each printing cycle a new piece of paper is brought between the two zinc plates, thereafter the zinc plates are brought together and in this way each printing cycle produces one complete page. The printing speed on this machine ("Heidelberger" book printing machine) is app. 20 sheets/minute.
One advantage of this method for braille production is the possibility of producing double-sided braille or interpoint braille. After one side of text is completely brailled on the zinc plates, the zinc plates are reversed and a second side of text is brailled from the other side on the same zinc plates. This is possible without damaging the text on the other side (the "first" side) by displacing the second side of text over exactly half the brailledot-pitch, both vertically and horizontally, with respect to the position of the text on the other side. While reading a side of the interpoint braille, the text on the reverse side presents no problem to the reader, while holes in the paper can hardly be felt.
This being a rather satisfying production method for large quantities of a given text, the solution for smaller amounts of a certain text is less satisfying up till now. The method of production that is used here, employs the same brailling devices (with one exception) that are used for manual production of braille. The essential pieces of equipment here originate from three sources: the makes "Perkins" (American), "Lavender" (British) and "Blista" (German).
Of these three devices, the one made by "Blista" is the only one that operates with a platen that moves from right to left in order to transport the place where the new braillecell is to be brailled under the fixed mechanism that performs the actual brailling operation. Hence the paper is moving from right to left during the brailling of a line, and this makes this machine rather unfit for an automated approach, because of the problems that arise with the papersupply, when working with paper in continuous form coming from a large roll or with fanfold continuous form paper. So the machines usually taken as a basis for some automation of the production process, are the ones from "Perkins" and "Lavender". These two handbraillers have a brailling mechanism that moves along the line, while the paper remains stationary and are equipped with a braille keyboard. A braille keyboard consists of six keys and a spacebar. Each key is connected to an embossing mechanism which produces one specific brailledot from a braillecell. So the operator has to know the braillecode and assembles each symbol by simultaneously depressing the necessary keys for each dot. The usual procedure for automation of this process, is converting the information from

the input medium into mechanical movements (for instance by using solenoids) and linking these movements to the brailler, either from the outside to the braille keyboard or somewhere inside to the selection system that is connected to the actual embossing mechanism. With some modifications of the paper-transport system continuous form paper can be used, instead of the usual sheets. If this paper is coming from a roll a cutting device is added after the brailler, to separate the individual sheets of text; otherwise (when using fanfold paper) this is done on a separate burster/stripper.
The speed on these "electrified" handbraillers can reach a value of about four braillecells per second. Of course this is a large improvement over manual brailling, however the production of e.g. hundred sheets of braille with this speed still takes about eight hours. So this kind of equipment is used fairly intensive to satisfy the demand of braille in smaller quantities, operating at loads and speeds this equipment was probably not designed for. This leads to increased wear and to a deterioration of the reliability.

The exception already mentioned above is a device, which can be used for braille production, that is not an electrified handbrailler but was designed as a high speed braille computer terminal. This terminal (LED 120, manufactured by Triformation Systems, U.S.A.) can be used as a stand-alone braille production device as well. It operates at a speed of 120 braillecharacters per second (three lines/s) on standard braillepaper in fanfold form. This terminal was not yet on the market when our basic research was started in late 1973, but was introduced in 1975. The reliability of this terminal and the quality of the braille it produces, made us decide to continue our research and development.
The "Perkins" handbrailler operates in the following way: the selection system sets the pins, for those dots that are to be embossed in the paper (max. 6), to a position about 1 mm above the position of the pins that are not wanted to emboss a brailledot. After this an embossing die is brought down on the other side of the paper and the complete braillecell is formed.
Then the embossing head moves one pitch to the right, ready to emboss the next braillecell. Both the holes in the embossing die and the tops of the embossing pins are adapted to the form of the brailledot that they are making.
The "Blista" and "Lavender" braillers work in a similar fashion.
The LED-120 terminal has more printing positions along the line and can therefore operate at much higher speeds. The device is equiped with 80 pins, with rounded tops that are positioned in a line at different distances,

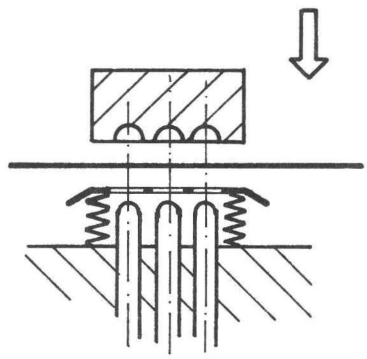

FIGURE 3

Embossing mechanism of the "PERKINS" brailler.

corresponding with a horizontal cut through a braille line of 40 characters. A complete line of braille can be made by operating these 80 pins three times and transporting the paper twice over the vertical brailledot pitch. As shown in Fig. 4 the brailling pins can be moved, because they are attached to the moving part of a solenoid by a lever. When a solenoid is energized, the plunger is attracted, the lever pivots around its pivotpoint and lifts the corresponding pin. The end of this movement is reached when the dot is formed and there is no more free space between the brailling pins, the paper and the beam on top of the paper, containing 80 spherical holes.

1.3.2 Analysis of brailling processes.

An important point that all these braille production machines have in common is the fact that the stroke of the brailling pins (and thus the resulting height of the produced brailledot) is normally limited by the collision of pin and spherical hole in the die, with the paper to be deformed in between, but only if the force driving the brailling pin is large enough to deform the paper until this point. If this is not the case, the movement of the brailling pin stops earlier (when the driving force of the pin equals the reaction force the paper exerts on the pin) and a dot with smaller height results. In both cases the movement of the brailling pin stops when there is a balance in the forces acting on the pin. Therefore this system of brailling will be referred to as "force-controlled". (In German literature this is called: Kraftschluss.)

One aspect of paper that was not mentioned until here, is the property that is has no constant composition over its surface. Both composition and structure differ from

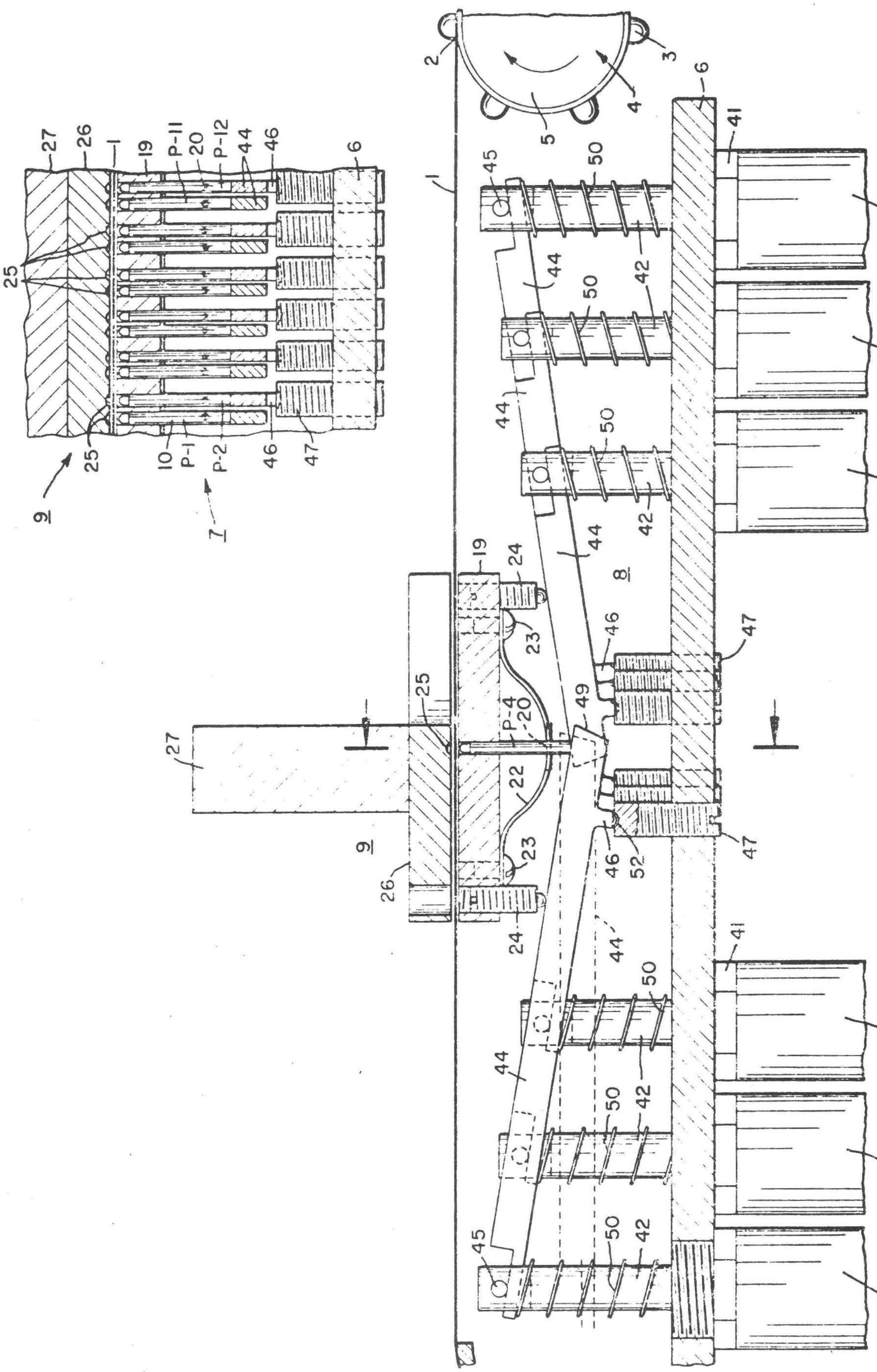

FIGURE 4

Operating principle of the LED-120 (from "LED-120 Manual").

place to place. This implies that the force needed to produce a brailledot of a certain height is different too, from one place to another. The only solution to this problem in a force-controlled system of brailling is supplying so much energy to the brailling pins, that the force reaches the necessary value to produce a dot of sufficient height, even under worst case conditions. This means however that under average conditions, the amount of energy supplied is too large for deforming of the paper alone, and the remaining energy has to be dissipated elsewhere, normally in a collision of the moving parts and the stationary die.

This of course means noise and extra wear. When a lot of these collisions take place in a certain timespan, this influences the sound level the brailling device is producing. In addition there is the problem that the amount of mechanical energy that can be supplied by a fast acting and therefore small system is small too. So when using a heavy grade paper (up to 160 grams/m^2) the amount is only just sufficient. This leads to unsufficient height of the produced brailledot under "worst case" conditions e.g. a particular brailling system with high friction forces or a spot on the paper requiring more brailling energy because of a different composition. This fact is demonstrated by a carefull examination of the output of for instance an LED-120 braille terminal. It is clearly visible that the dotheight, an important quality aspect, is not constant for all the dots in the text.

There is an answer to this problem: when the stroke of the brailling pins is not controlled by a force driving them, but when the stroke is dictated by the displacement of the parts that the pins are in contact with, the final height of the produced brailledots is always constant. Now the displacement is the independent variable and the force reached with this displacement is a dependent variable, depending on the displacement of the brailling pin and the properties of the paper on that spot. Because the displacement can be assured by the form of the driving parts (as will be demonstrated later) this system of brailling will be called: "form-controlled" (German: Formschluss).

In a form-controlled system of brailling the displacement of the brailling parts is always constant and not dependent on the (inhomogeneous) properties of the used paper. When a construction is used for example as sketched in Fig. 5, the stroke of the brailling pin is always the same regardless of the forces acting on the pin, as long as the cam is rotating and the pin keeps in contact with the cam. Probably this system of brailling was never introduced before, because the forces in the brailling system rise to very high values when the adjustment is not correct and a die is used that has a

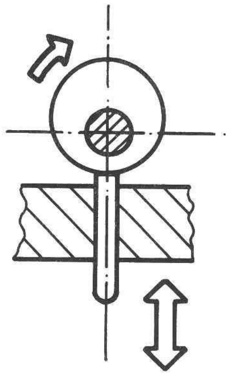

FIGURE 5

Form-controlled brailling system.

spherical hole conforming to the form of the top of the pin. In this case when the stroke is too large the resulting forces may even damage the machine. This adjustment problem can be avoided by using a die with a cylindrical hole in it, that is sufficiently longer than the height of the produced brailledot. In this way brailling pin and die are never in contact with each other, not even when the stroke of the brailling pin is larger than nominal, this just produces a higher brailledot. A second advantage of a form-controlled brailling system is the possibility to control the velocity of the brailling pin during its movement. In a force-controlled system the brailling pin is usually accelerated towards the paper and has its highest speed at the moment of collision with the paper. This impact produces noise. In a form-controlled system the complete stroke can be controlled and this makes it possible to decelerate the pin before it hits the paper, thus minimizing the impact noises. Such a form-controlled brailling system will be used in the braille lineprinter of which the design is described later on.

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2. MAIN DESIGN CONSIDERATIONS.

2.1. Specifications the printer must comply with.

From the description of braille as given in Chapter 1 it is obvious that, though there is no formal normalization in the dimensions of brailledots and braillecells, a new braille producing piece of equipment must produce braille that has dimensions close to the ones that were established through the years by other manufacturers. The braillecell that was chosen here has a vertical dotpitch of 2.5 mm and a horizontal dotpitch of 2.4 mm. In the original design the horizontal pitch was 2.5 mm too, but with a braillecell-pitch of 6 mm, the difference between two dots from one cell (2.5 mm distance) and two dots from different cells (3.5 mm distance) proved to be difficult to discriminate. Reading tests with experienced braille readers (both congenitally blind and late-blind) showed that they had a preference for a larger "space" between the individual braillecells. So the distance of 2.4 mm was chosen. (This value lies between the corresponding values of the "Perkins" and "Blista" braillecells.) This preference for a larger space between the braillecells is probably partly caused by the relatively large amount of "Perkins" braillers that are used in the Netherlands, and to the format this machine produces, to which the users get accustomed.
For the linespacing a value of 10 mm was chosen, which is a multiple of the vertical dotspacing, facilitating the necessary papertransport mechanism. In this way it is possible to reduce the number of necessary components in the printer by using a sort of mechanical multiplexing. Instead of having 240 embossing possibilities in the device, only one row of brailling pins has to be present (a total of 80 pins) and a complete braille line is built up by embossing three times, using the same set of pins but with two papermovements (vertically) between the three embossing cycles. After embossing the last row of brailledots a papermovement of 5 mm provides for the spacing between the lines and the machine is ready to emboss the next line. In the list of specifications that has to be compiled at this stage, those features directly influencing the quality of the produced braille certainly may not be missing. In order to set a quantitative standard for the two principal properties of the produced braille, the relative position of the dots and their height, an inaccuracy of 10% is tolerated. From the measurements performed on braille from the most widely used braillers it can be concluded that this tolerance in height of the dots would be a definite improvement. Our readingtests with braille that contained inaccuracies

in the relative position of the brailledots, (these inaccuracies were produced on purpose and their values were known to the conductor of the tests, not to the readers) proved that randomly distributed deviations from the nominal dotpositions were not noticed by the reader, when there value did not exceed 0.35 mm. Even a systematic variation of $\pm$ 0.35 mm in the vertical dotpitch for a complete horizontal row of dots in one line was not noticed. (This type of misaligning might be introduced by for instance play in the papertransport mechanism.)
As a result of these tests the tolerance for both position and height of the dots was set to 10%. For the position of the dots this means a tolerance of $\pm$ 0.25 mm and for the height a value of $\pm$ 0.05 mm.
A deviation from the nominal linespacing of 10 mm is less disturbing to the reader because braille is read on a line by line basis and mispositioning of a complete line does not influence the legibility of the line itself because the coherence between the dots within one cell is not influenced. Therefore the allowed tolerance in the linespacing is set to 0.5 mm (twice the value for the spacing between dots within one cell).

Another phenomenon which may influence the quality, but on the long term, is the paperdust that is produced when the brailledots are formed. During the last stage of the forming process of the actual dot, the paper at the top of the dot is slightly torn and this produces paperdust. Because of the composition of paper, this dust usually contains some amount of chalk which is added as a filler to the basematerial cellulose. This chalk in particular can be a serious source of wear when it gets between sliding parts . The paperdust itself, when trapped in a small clearance, might clog together and increase the frictionforces even to the extent that, when sliding parts are moved with fixed low forces, no more movement is possible. This could happen for instance in a system with the brailling pins sliding in drilled holes, when one does not take the necessary precautions, because the dust producing source is so close to the clearance between pin and hole. In a fast braille producing device some precaution against paperdust should always be taken. (In low speed machines one might solve this problem by regular maintenance intervals, at which the threatened places are cleaned.)
For the number of characters that the printer should be able to print on one line the value of 40 was chosen. This number is the usual value in braille producing equipment both European made and American made, although in Europe hardly ever more than 32 positions are used, usually to create a wide left margin to facilitate binding. As to the size of the paper that is

currently being used, again there seems to be no formal normalization. For bookproduction in the "Dutch Library for the Blind" at The Hague a paperwidth of 250 mm is used. The standard paperwidth used on the LED-120 lineprinter there is 11.5 inch (292 mm). This width includes the extra paper on both sides containing the pin-feed holes for the papertransport system. The custom in the U.S.A. however on this type of equipment is to use the same 11.5" paperwidth but to add the width neccessary for the pin-feed holes, leading to a total paperwidth of 12.7" (323 mm). The maximum paperwidth to be used on the printer under consideration here is set to 14" (356 mm).

Another important feature when someone is using the lineprinter in a terminal configuration (for instance in conversational computer use) is the accessibility of the last line of braille that was printed. It should be possible to read the last line completely once this line has been printed. To achieve this, care should be taken in designing the system in such a way that the last line is presented at an angle to the user that makes the text easily readible.

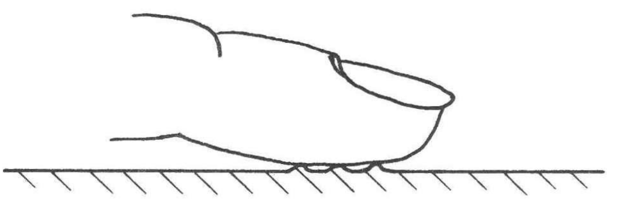

FIGURE 6

Position of the finger, while reading braille.

It should be noticed here that braille is usually read with the underside of the last phalanx rather than with the top of the finger. It should be possible to reach the last line at such an angle that this is possible.

The braille production speed of the device is set at this stage at 300 lines per minute, of course maintaining the already defined quality standards. From our first experiments it seemed that this speed could be attained, using conventional electro-mechanical actuators.

So far these considerations have only dealt with the output side of the lineprinter. To make it possible to produce output, the specifications for the input should be standardized as well. At this point a choice has to be made for the device to be designed: either a braille lineprinter or a braille terminal. The braille lineprinter was chosen here for two reasons:

- a lineprinter is easier to test once a prototype has been built;
- the original request was for a lineprinter.

Furthermore the mechanical part of a lineprinter is not necessarily much different from the mechanical part of a terminal, when it is known from the start that the same basic unit should serve both functions. The most important difference concerns the interface, the adding of a keyboard and the different functioning of the device, but this is accomplished by changing the control electronics, not the basic mechanical unit. This is the reason that an interface was chosen that would enable the lineprinter to operate as a stand-alone unit, making other equipment in a test set-up (such as a computer) redundant.

The interface chosen is a FACIT SP 1 interface; this is an eight bit parallel data transfer interface. A detailed description of the FACIT SP 1 interface can be found in Ref. 4.

This interface enables e.g. a FACIT 4020 tapereader to operate as input device. This is a medium speed (maximum 300 characters per second) optical papertapereader, fast enough to feed the lineprinter at a sufficient rate.

The considerations mentioned up till now can be summarized as follows:

Interface:	FACIT SP 1
Printing speed:	Up to 300 lines/minute
Max.number of characters per line:	40
Line spacing:	10 mm ($\pm$ 0.5 mm)
Character spacing:	6 mm ($\pm$ 0.25 mm)
Braillecell dimensions:	2 x 3 matrix
horizontal pitch:	2.4 mm ($\pm$ 0.25 mm)
vertical pitch:	2.5 mm ($\pm$ 0.25 mm)
dot height:	0.5 mm ($\pm$ 0.05 mm)
Paper format:	continuous form, fanfold
width:	8"-14" (200-360 mm)
weight:	up to 160 grams/m^2

2.2. Division into information and energy converting parts.

A usefull division which can usually be made in finemechanical equipment is that between energy converters and information converters (Ref. 5). In this case the total device would be classified as an information converter. In order to get an impression of the energy levels that are associated with this information conversion, the energy necessary to form a brailledot is determined. Fig. 7 gives the result of measurements of the force while embossing a brailledot of the nominal size (0.5 mm high and 1.4 mm diameter) as a function of the displacement of the braille pin. Two facts can be concluded from this picture:

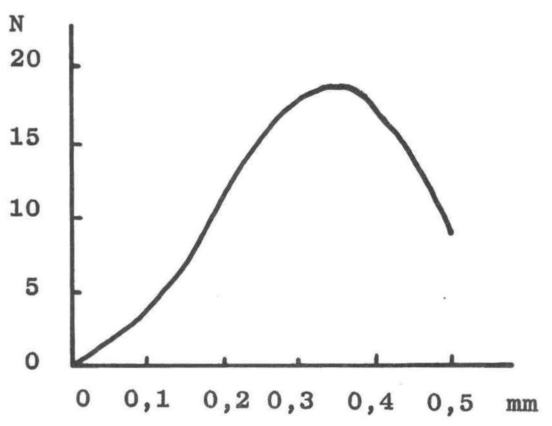

FIGURE 7
Brailling force as function of the produced dotheight (Paperweight: 160 grams).

- The maximal force encountered during the formation of a brailledot amounts to ca 20 N.
- The amount of energy necessary to produce one brailledot of the nominal size is ca 6 mJ.

Compared to the amount of energy required for the printing of a complete character on a "black-print" lineprinter, using normal ribbon, this is about the same (Ref. 6/7). However the process is completely different: The stroke is much shorter, resulting in forces that might easily be ten times as high. So the energy requirement for a braillecell consisting of all six dots could be six times the value mentioned above. For a speed of 300 lines per minute, each containing maximal 40 characters, the necessary mechanical power can be calculated to be 7.2 W.

For an information conversion alone this is a rather high value, so the point can be raised whether it could be advantageous to make a separation between the information processing parts in the lineprinter and those parts that are responsible for this energy conversion. The definition of the information processing function here, is the actual selection of those positions where a brailledot should appear on the paper, the energy converting function is performed by the actual brailling mechanism. There is another phenomenon which points in the same direction. Other research indicates that the efficiency with which electrical energy is converted into mechanical energy increases with the size of the electro-mechanical converter (Ref. 8). So it is much better to have one (large) electro-mechanical converter supplying the brailling energy and a selectionsystem deciding to which positions on the paper mechanical energy should be directed, than for instance 240 resp. 80 small electro-mechanical actuators, each converting the electrical energy for the embossing of one brailledot and selecting brailledots by switching on and off these electro-mechanical actuators. In the first case the efficiency of the total system will be better.
Of course, as will be shown in later chapters, when a large electro-mechanical converter is used, one still needs a large number of small electro-mechanical actuators to perform the selectionfunction, and these actuators have a poor efficiency. But because this difference in energy level exists between the brailling system and the selectionsystem, the amount of energy that is lost is still smaller, resulting in a better efficiency for the total system.
The reason for paying so much attention to the system efficiency is in the fact that electro-mechanical actuators with less energy losses can be stacked closer together. This means smaller moving masses connecting the actuators to their operating area. This results in higher overall operating speeds.

3. THE BRAILLING SYSTEM.

3.1. The brailling elements.

The principle of form-controlled brailling, as was introduced in Chapter 1, is implemented here for the case of a braille lineprinter. The optimal dimensions of braillepin and corresponding die have been found from tests that were carried out with different sizes of pins and holes, to see what size would fit a form-controlled brailling process best. The dimensions that produced a brailledot of the nominal size, as indicated in Chapter 2, are stated in Fig. 8.

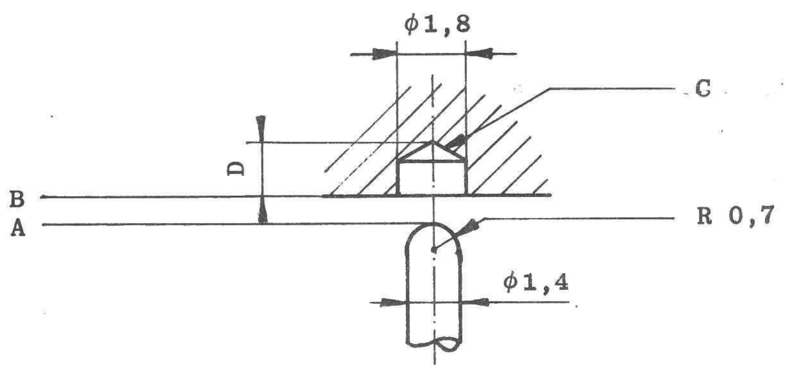

FIGURE 8
Dimensions of the braille producing parts.

The correct height is produced when the top of the brailling pin (level A) is moved upwards until the bottom of the corresponding hole (level B) is passed over a distance of 0.4 mm. The depth of the hole should be such that in this position there is no contact between the end of the hole (surface C) and the top of the produced brailledot, not even when using the thickest kind of paper. This implies a minimal holedepth (size D in Fig. 8) of 0.5 mm. For a good form of the brailledot, it is essential that the centerlines of hole and pin coincide. Because braillepin and hole are moving relative to each other during brailling, this is not merely a question of good positioning of these parts but also of a reliable bearing system. The best position for a bearing of the pins is as close to the top as possible, but this is also the most dangerous spot with regard to the produced paperdust. Therefore a bearing is chosen that is not at all sensitive to dust: each brailling pin is guided by two leaf springs, enabling axial movement of the pin by elastic deflection. Such a parallel guide mechanism guides the pins but the movement is not rectilinear. The deviation from the straight line is given by Hildebrand (Ref. 18) as:

$$v = \frac{3}{5}\frac{f^2}{\ell} \qquad (3.1)$$

with v = deviation from the straight line

f = deflection of the leaf springs

ℓ = length of the leaf springs.

This does not matter for the bearing of the pins, because they are standing still during the formation of a dot. This can be accomplished with a set-up as shown in Fig. 9. Each brailling pin guiding is slightly prestressed because in the top position of the pins the lower leafsprings are in contact with a fixed shaft A that gives all pins the same height.

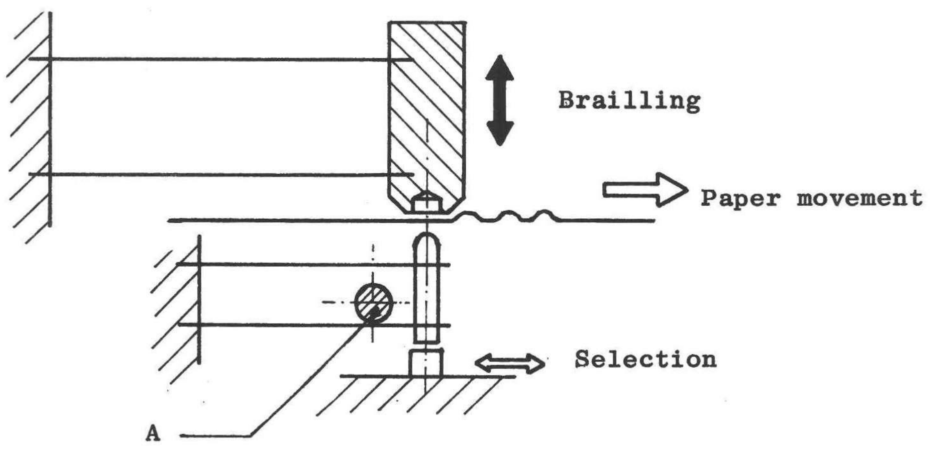

FIGURE 9

Bearing system for brailling pins and beam.

On top of this a beam is mounted, in its lower surface containing holes corresponding with the position of the pins, performing the brailling operation when it comes down. To be able to make a selection between pins that should produce a brailledot and those that should not, small blocks are added that can move perpendicular to the movement of the brailling pins and the brailling beam.

When the brailling beam moves downward, the play on both sides of the paper, between holes and pins, is decreased till zero and then the pins start moving downwards. When a dot should be produced, the selectionblock is manoeuvred under the pin, and when the play between underside of the pin and selectionblock has disappeared, further downward movement of the pin is blocked and a brailledot is formed. For those pins that should not produce a dot, the selectionblock is moved away from under the pin so the pinmovement is not blocked. The leafsprings that guide the pins are so dimensioned, that even in their lowest position, they exert a force on the paper that is still so small that the paper is not deformed and stays flat.

The guiding of the brailling beam is designed as a leafspring parallelguide as well. However here, when the brailledot is formed, the beam is moving downwards, so the deviation from the straight line is present during brailling, causing a misalignment of holes and pins. Therefore the length of the leafsprings guiding the brailling beam is chosen larger than the length of the leafsprings for the pins, and in this way the misalignment caused by the curved movement of the beam is limited to 0.015 mm. This produces no substantial deviation from the nominal dot form.

More information concerning the dimensioning of bearing systems employing elastic deflection is gathered by Breitinger (Ref. 15).

Another important decision that has to be made concerns the number of pins that should be present in the printer and the number of pins that should be brailling simultaneously. The structure of braille, each cell consisting of a maximum of six similar dots, already suggests that some form of multiplexing should be possible. The number of pins that is chosen for the printer is 80, positioned in one straight line in 40 groups of two, each group having the possibility to produce one third of a complete braillecell in one stroke. In this way the leafsprings for the pinbearing can be clamped in a simple way. In order to attain the final speed of five complete lines per second (300 lines per minute), these 80 pins have to be operated 15 times per second. If the driving mechanism is operating continuously, this speed should not present a problem. For the selection of the brailledots the selectionblocks have to be operated 15 times per second as well.

Because these movements can not be predicted beforehand, while they depend on the information to be printed, the movement of the selectionblocks will be discontinuous. But the selectionblocks that are necessary are small (diameter 2 mm, height 2 mm) and so is their mass (50 mg) so it should be possible to move this mass at this speed using normal electro-mechanical actuators.

For the paper transportsystem this way of working means that the paper is not transported over the linespacing of 10 mm in one operation, but that this movement is divided over three smaller movements. With a numbering of the brailledots as indicated in Fig. 10, the paper is transported after

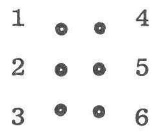

FIGURE 10

Numbering convention of the dots within a braille cell.

the brailling of dots one and four over a stroke of 2.5 mm, the same after brailling dots two and five and finally over a stroke of 5 mm when dots three and six have been made. The printer is now ready to start brailling the next line. So brailling the complete line in three cycles does not change the average speed of the paper transportsystem.
The final influence of the choice of only 80 brailling pins instead of 240, that should be discussed here, is the impact it has on price and reliability. If the price of a complete selectionsystem is estimated to be somewhere about Dfl. 20,-- and the cost for the associated driver electronics to be Dfl. 10,-- (component costs, manufacturing costs, assembly costs, etc.), chosing 80 pins instead of 240 will decrease the costs of the total system with Dfl. 4.800,--. Since reliable operation of the printer depends on the reliability of all selection systems, (for a reliability analysis all selection systems can be assumed to operate in series), the reliability of the printer can be found as the product of the reliabilities of all selection systems (assuming here that these systems are the only ones influencing reliability). When for example R(100)=0,999 for one selection system (this indicates that from a population of identical selection systems 99,9% is still functioning after 100 hours), the R(100) value for the complete printer is improved from 0,786 till 0,923. If a constant failure rate is assumed, this means that 80 selection systems with a MTBF of 10^5 hr each, will lead to a printer with a MTBF of 1250 hr, instead of 417 hr with 240 selection systems.

Another point that has to be decided on, is the choice of a mechanism that will drive the brailling beam. The best solution for a fair price is an electric motor when the movement may be continuous. The conversion from the rotary motion of the electric motor into the oscillating motion of the brailling beam is performed by the mechanism that is depicted in Fig. 11. A shaft driven by means of a belt by the electric motor contains two

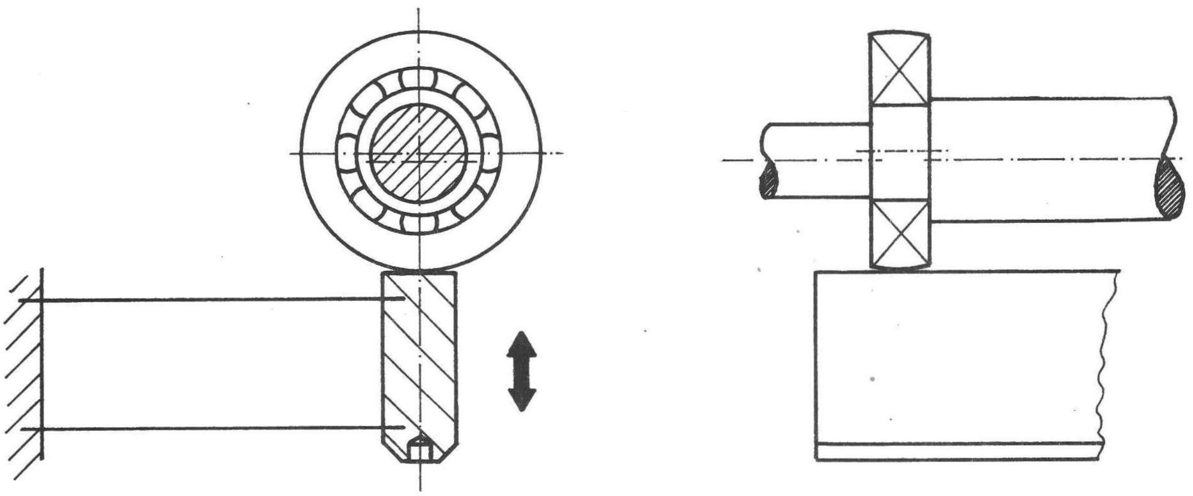

FIGURE 11

Activation of brailling beam.

eccentric parts, on which "rollers" are placed.

These are special (sealed) roller bearings from which the outer ring is thicker than normal, so the load to the bearing can be applied as a concentrated load at one point of the circumference of the outer ring. This does not cause such a deformation of the outer ring that the lifetime of the bearing is substantially shortened, as would be the case with a normal roller bearing. The form of the outer ring can be a little spherical to avoid alignment problems. The inner ring of the bearing is rotating with the same speed as the shaft, the outer ring is standing still because it is in contact with the top of the brailling beam. While the brailling beam is making its up and down movement, the outer ring of the bearing is rolling from left to right and vice versa over the top surface of the beam, with of course the same stroke as the vertical movement. Because there are no sliding parts involved in this construction, only rolling action, there is a good guarantee that the stroke over which the brailling beam is moving will not decrease with time. This would of course directly influence the height of the produced brailledots.

Detailed calculations of the deformations that occur during brailling in all parts of the brailling mechanism are given in Appendix 8.6.

3.2. Description of the brailling system.

Drawing 8.1.1 gives a cross-section of the brailling assembly. This unit consists of two sub-assemblies: The brailling frame (beam 47, sideplates 3 and main shaft 5) and the braille forming system (brailling beam 6, 8, 15 and brailling pins 25). Both sub-assemblies can be built up outside of the lineprinter and all necessary adjustments can be performed at this stage. Both units are then mounted against the selection-sub-assembly (described in Chapter 4).

3.2.1 The brailling frame.

The main frame of the brailling system consists of a fixed beam (partnr 47), two sideplates (partnrs 3) and the main printer shaft (partnr 5). These are all steel parts. Each of the two ballbearings that are used to support the main shaft, is mounted in one sideplate (partnr 3) using an eccentric bushing. By rotation of these bushings the position of the main shaft can be changed and in this manner the resulting height of the braille dots can be influenced. So only two adjustments are necessary to correct the braille-dot height over the complete line.

3.2.2 The braille forming parts.

The brailling beam consists of three main parts: an aluminium middle part (partnr 8) and two steel beams (partnrs 6 and 15), that are bolted together at the same time clamping the four leaf springs (partnrs 62) that provide the bearing for the movement of the brailling beam. This composition of the brailling beam produces a large bending stiffness without adding too much mass. The left side of the brailling beam is kept in contact with two rollers (partnrs 4) mounted on two eccentric parts of the main shaft by means of two helical springs (partnrs 14).
The stainless steel brailling pins (partnrs 25) are mounted between the fixed beam and the brailling beam by means of leaf spring "combs" (partnrs 27). These are "comb"-like structures, etched from spring steel plate, which are glued to the brailling pins and act as a parallel guiding for each pin. Each leaf spring comb has twenty teeth, so the complete row of eighty pins uses 4 x 2 combs. They are clamped together at the base of the comb. A square steel beam (partnr 28) covered with a damping rubber sheet (partnr 30) assures that all brailling pins take the same axial position because their leaf springs are prestressed and in contact with this beam.

In this fashion the clearance is adjusted that exists between the right-hand ends of the pins and the left-hand surface of beam 47. In this clearance (when the brailling beam is in its left most position) the movement of the selection blocks takes place.
The base block for clamping of the leaf spring combs forms one assembly with two aluminium sideplates (partnrs 134) and an aluminium beam (partnr 26), which has a window-like appearance. This window is closed by a silicone rubber dust cover (partnr 38) that protects the selection system from the dust that is produced during brailling. The brailling pins protrude through this cover to the right.
The side of the brailling beam that is facing the brailling pins, is covered with four spring steel plates (thickness 0.8 mm), each containing twenty holes (diameter 1.8 mm) of which the centerlines coincide with the center-lines of the brailling pins. These plates are etched also, using the same mask that contains the pattern for the leaf spring combs (partnr 27), so if there is any inaccuracy during the reduction phase of the masks, both holes and pins share the same inaccuracy, causing no change in their relative position. Furthermore the clamping blocks for all leafsprings, guiding brailling pins or brailling beam are bolted together, via the parts numbered 68 and 70.
The sections that are used to guide the paper through the lineprinter are:
A funnel-shaped assembly of aluminium plates (partnr 81), enabling an easy input of the first sheet from a new box of paper, an aluminium T-shaped beam (partnr 23) with a lifting plate (partnr 22) glued to it, to lift the paper from the tops of the brailling pins after each brailling cycle and the curved parts (nrs 20 and 24) that bend the paper, after it has been brailled, in the direction of the papertractor mechanism (partnr 34). All parts that are in contact with the paper when this is transported, are covered with either "Teflon" tape or coated with "Teflon" spray to reduce the friction forces between the sliding surfaces. The strip with partnr 114 is functioning as a sealing against paper dust, protecting the selection system.

4. THE SELECTION SYSTEM.

4.1. The selection process.

As mentioned in Chapter 3 the individual brailledots may be selected by moving a small block underneath the corresponding brailling pin or not. The dimensions of these blocks must be chosen in such a way that the complete stroke of the brailling beam can be made without deforming the paper when the blocks are in the "not-selected" position. This can be accomplished by using cylindrical blocks (which are easy to fabricate) with a diameter of two mm and a height of two mm too. If these blocks are positioned with their centerlines coinciding with the centerlines of the brailling pins, as shown in Fig. 12, a positioning inaccuracy of 0.3 mm can be tolerated in all

FIGURE 12

Position of the selectionblock relative to the pin position.

directions, still maintaining the full bottomsurface of the brailling pins to pass the load to the fixed support. With a stroke of 2.5 mm for all selectionblocks, there is a tolerance of 0.8 mm in the "not-selected" position before the brailling pin hits the selectionblock and an unwanted dot is brailled.

At this point again, considering the number of selections that have to be made for each brailling cycle (80 independent movements), the point can be raised whether 80 similar selectionsystems should be present in the printer or that the price and the unreliability of the equipment can be further decreased by applying some form of multiplexing. If a system is designed that enables movement of the selectionblocks in two directions which are perpendicular to each other, one selectionsystem can be used to select two dotpositions. The dimensions of the braillecell in fact already suggest such a solution.

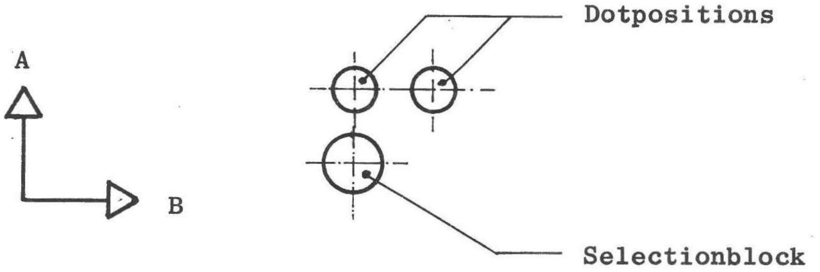

FIGURE 13

Definition of the directions of the selection movement.

If a guidingsystem can be devised that guides 40 selectionblocks in the A-direction (Fig. 13) and this system as a whole can be moved in the B-direction, 40 selectionsystems can select 80 dotpositions. The movement in the A-direction will be the actual selectionstroke (placing the blocks under a pin or not), while the stroke in the B-direction causes the blocks to alternate between the "left" and "right" braillepins which are to produce one half cell each. Another important argument for this reduction in the number of selectionsystems is the available space in the lineprinter. If forty selectionsystems have to be accomodated in the printer, the available space along the linelength is increased till 6 mm. This is just sufficient to employ the slimmest commercially available electro-magnet.

Again assuming a reliability of 99.9% for each selectionsystem and the same reliability for the mechanism that causes the movement in the B-direction, the overall reliability (R(100)) can be increased from 92% till 96%. The stroke of the system for the B-direction is about the same (2.4 mm) as the stroke in the other direction, but of course the mass that has to be moved is at least 40 times as large, because all 40 blocks have to move at the same time. The actual mass in the printer is still larger because the guiding system for 40 movements in the A-direction will have some mass too. Because the movement in the B-direction only has to discriminate between two positions this system will be called the duplex-system, and the mechanisms causing the movement in the A-direction will be called "the" selectionsystems. If the speed of these selectionsystems is not doubled compared to the speed they should have in a printer without duplex-system, the outputspeed of the

complete printer would drop to half the initial value. So the specification for the speed of the 40 selectionsystems has to be doubled to maintain an outputspeed of five lines per second.
(It should be stated at this point that increasing the speed of a mechanism might have an adverse effect on its reliability, meaning that the above mentioned reliability calculations are no longer valid.)
A guiding system that can guide all 40 selectionblocks in two mutually perpendicular directions can be constructed in the following manner (Fig. 14):

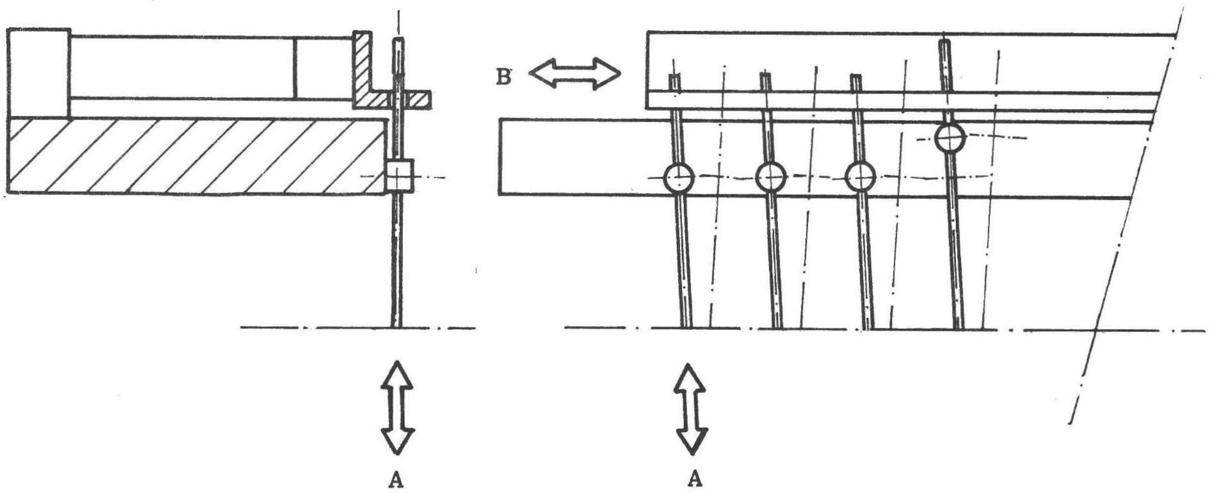

FIGURE 14

Operating principle of the selection mechanism.

If all selectionblocks are provided with small holes, perpendicular to the centerline, wiresprings can be attached to these blocks by glueing.
If these wiresprings are put through a beam containing 40 holes that are somewhat larger than the diameter of the wiresprings, the wiresprings can be moved in the direction of their length (they slide through the holes) but the position of the hole is the guiding mechanism for this movement. If the beam containing the 40 holes (the duplex-beam) is moved along its length (direction B in Fig. 14) different paths of the selectionblocks during the selection movement are possible.
If the length of the wirespring is sufficient, the point of introduction of the "A"-movement does not have to move in the B-direction as well, because the difference is taken up by bending of the wiresprings. So the 40 selection systems can remain stationary, while the result of their action (the position of the selectionblocks) can be doubled. In this fashion each selectionblock can reach four positions. By suitable dimensioning of length and diameter

of the wiresprings the resulting bending moment at the point of connection to the selection systems can be kept to an acceptable limit. Because of the fact that the guiding mechanism for the duplex movement (the duplex-beam) is at some distance of the elements of which it should control the position (the selectionblocks), an inaccuracy might be introduced, so especially the dynamic behaviour of such a mechanism should be analysed. Vibrationmodes of the wiresprings might create discrepancies between the wanted positions of the selectionblocks and their actual position.
Another advantage of a guiding system employing wiresprings in holes, is that the guiding is not limited to one direction (the duplex direction) but can also be applied to a direction perpendicular to both duplex direction and selection direction, in other words it can control the height at which the selectionblocks are moving. This ability will be used here to keep the selectionblocks close to the surface of their supportbeam, this will keep the clearance between the top-surface of the selectionblocks and the brailling pins at the right value. The size of this clearance is important in the timing of the movements of selectionblocks and brailling pins relative to each other. The selection movements (in both A- and B-direction of Fig. 14) should be completed, when the clearance starts decreasing, otherwise the selection systems might get damaged.

4.2.1 Possible concepts for the duplex system.

At this point we can define two mechanisms that, when working together, will operate all 40 selectionblocks in the way described above. One mechanism is necessary for driving the duplex-movement, forty similar mechanisms are wanted for the actual selection. The specifications for the duplex-beam driving mechanism are:

Stroke of the mechanism:	2.4 mm
Allowed time for this movement:	22 ms
Rest time:	11 ms
Total cycle time:	33 ms
Mass to be moved:	30 grams.

The cheapest way to realize this part of the selectionsystem would be to connect the duplex-beam to the plunger of a solenoid. Because these actuators have a non-linear force-stroke relationship the best system would probably be to use two solenoids pulling the duplex-beam alternating from left to right. If a parallelspring guiding is used to guide the movement of the duplex-beam, the springrate of this mechanism could be chosen to match the characteristics of the solenoids to obtain a smooth movement of the beam. If the resonance frequency of the duplex-beam is properly tuned, the speed at both end stops would approach zero and the noiselevel should be acceptable. For tests such a system was designed and evaluated. As solenoids two "Harting 08 20607 2028" solenoids were used. These are general purpose plunger-type solenoids with a power rating of 16 Watts for a 50% duty cycle. The plungermass of these solenoids is 45 grams, but this mass could be decreased till 21.5 grams. This was possible because the solenoids were used in a part of their characteristic where no danger of magnetic saturation of the plungeriron exists. This enabled the removal of a part of the core of the plunger without a deterioration of the magnetic properties. Both solenoids were equipped with end stops that were covered with a synthetic rubber layer of 1 mm with good damping qualities. This system was operated from a constant voltage source, switching both solenoids alternating on and off, producing a 50% duty cycle for each solenoid. Our experiments proved however, that this system could drive the duplex-beam with the right cycletimes, although there was a large phaselag between the voltage on the magnet coils and the actual plungerposition, but that for a reliable system the voltage had to be raised to a level where a collision with each end-stop occurred producing a noiselevel that could not be accepted in a piece of office equipment.

So the final design has a drivesystem for the duplex-beam that, though more expensive, offers reliable operation together with an acceptable noiselevel. The system consists of a shaft that runs at half the speed of the main shaft driving the brailling beam and on this extra shaft a cam with one of its axial surfaces containing the profile that is driving the duplex-beam. The duplex-beam is equiped with a roller that is kept in contact with the curved surface of the cam by means of a helical spring. This camshaft is driven from the main shaft by means of a timing belt so the synchronisation of the left-right movement of the duplex beam is assured.
Compared to a solenoid driving system this camdriven system has less flexibility in the choice of the brailling sequence. On each next brailling cycle the duplex-beam moves to the other side, so the brailling sequence has to be: dot 1-4-2-5-3-6. After the sixth cycle the duplex-beam moves to the left again and the system is ready for the selection of the next braille line. Had solenoids been employed the brailling sequence could have been: 1-4-5-2-3-6, 4-1-2-5-6-3. This would have halved the number of left-right

movements of the duplex-beam (Fig. 15).
This can be seen as another disadvantage of a camdriven system, although the control sequence can be more simple because the dot sequence is the same for each brailleline, where a solenoid system would be working with two different dot sequences.

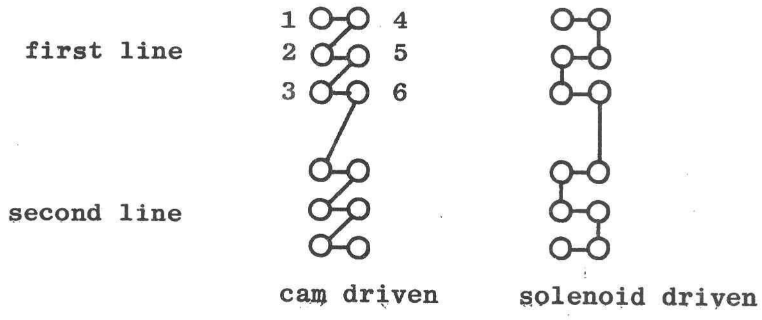

FIGURE 15

Two possible brailling sequences.

4.2.2 Possible concepts for the selection system.

The specification for the forty selection systems could be summarized as:

Stroke of the mechanism:	2.5 mm
Allowed time for this movement:	22 ms
Rest time:	11 ms
Total cycle time:	33 ms
Mass to be moved:	100 mgrams (block + wire spring)
Maximum size in one dimension:	6 mm.

The last point needs some explanation:
The introduction of the duplex-mechanism has increased the available space in the "line"-direction for each selectionsystem to 6 mm (the pitch of the braillecells). To keep the components for the forty selection systems cheap and similar for all forty, a set-up is prefered in which all systems can be stacked next to each other along the length of a line. This implies that the addition to the total length for each system may not exceed 6 mm.
As possible concepts for the electro-mechanical actuator with the specifications stated above, the following operating principles can be considered: an electrodynamic system (e.g. a moving coil mechanism), an electro-magnetic system or a piezo-electric system. An electro-dynamic system is normally used

in those applications where a linear current-force relationship is required, because the accuracy of the displacement is critical. This is the case in e.g. loudspeakers and moving coil meters. There the relative high price (because of the use of permanent magnetic materials) presents no problem. It would be different in this braille lineprinter because 40 systems are needed and they would have to be custom made. Therefore the idea of using an electro-dynamic system is dropped. In fact the only systems that are readily available are electromagnetic systems in the form of solenoids, and piezo-electric systems in the form of bimorphs or multimorphs. Because the piezo-electric effect is rather small the displacements of bimorphs or multimorphs are small as well (in the order of μm's). When a safety margin is kept between the voltage that depolarizes the piezo-ceramic material and the actual operating voltage, the stroke that can be obtained from a multimorph of 70 mm length (Philips stocknr 4322 020 04830) amounts to 1.25 mm (assuming a free length of the cantilever of 60 mm) at an operating voltage of 250 Volts (Ref. 14). This calculation assumes that the free end of the multimorph can move freely; when a force is applied to the free end the resulting displacement is smaller. For the system sketched in Fig. 16 the force necessary to obtain a displacement of 1.25 mm at point A can be

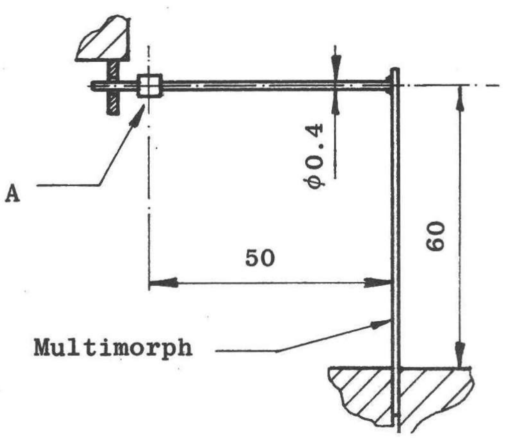

FIGURE 16

Outline of a piezo-ceramic selection system.

calculated to be about 12 mN. From Fig. 17 it can be concluded that this decreases the stroke of the element till about 0.8 mm. This limits the total stroke at a value of 1.6 mm. (Reversing the voltage reverses the output stroke as well.) This is only 75 % of the necessary stroke. Because multimorphs

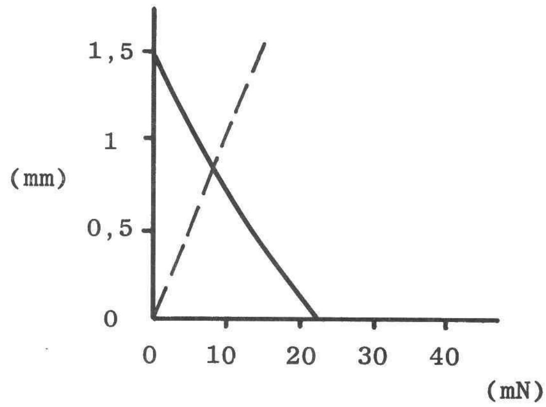

FIGURE 17

Stroke versus force of the multimorph from Fig. 16 (from Ref. 14).

of these lengths are very vulnerable, no effort was given to design some means of amplification of the stroke of such a mechanism.

For an electromagnetic system the displacement of 2.5 mm is a normal value while the speed of operation should not present a problem either for a small system. An indication for the possible operating speeds of small electromagnetic drive systems is given by Heider (Ref. 19) who states that systems with a stroke of 1.5 mm can still operate with a frequency of about 400 Hz. The possible operating frequency decreases when the stroke increases. However no cylindrical solenoid is commercially available with a diameter smaller than 6 mm, so a straight stack with this type is not possible. An electromagnet, on the contrary, can be small in at least one dimension. This type is suited for building a straight row of selection systems, if a magnet can be found thinner than 6 mm.

4.3. Final concept of the selection system.

If an armature is designed to work with the Harting magnet 08/01501/0107, the easiest movement for this armature (with respect to the design of a bearing system) is a small rotation. For this purpose the armature can be attached to a leafspring, that positions the armature in front of the poles of the electromagnet, enables a small rotation and delivers the restoring moment necessary to rotate the armature back to its starting position when the magnet is de-energized (Fig. 18).
With an armature of 25 x 4 x 1 mm and a leafspring with length 10 mm, width 5 and thickness 0.2 mm the fundamental resonance frequency is 77 Hz, so the

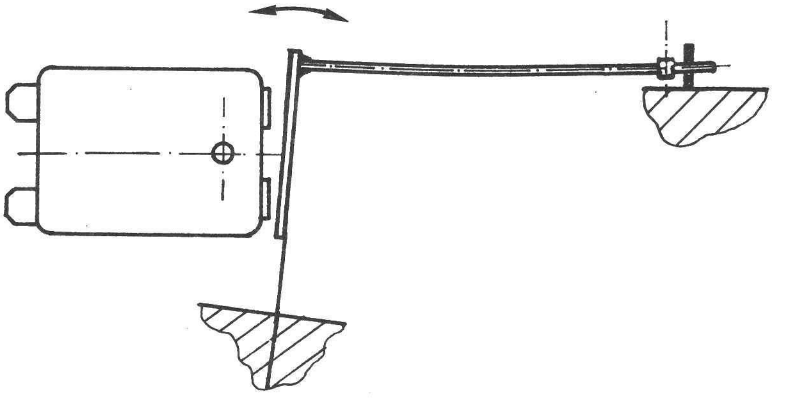

FIGURE 18

Selection system employing an electromagnet.

necessary speed should not be a problem. If for example the complete stroke of the armature should be made in 10 ms (maintaining a certain safety margin) an estimate can be made of the amount of mechanical energy that is required: If it is assumed that the armature is accelerated during the first half of its stroke with a constant acceleration and the second half of the stroke decelerated with the same deceleration the necessary mechanical energy can be calculated to be about 0.1 mJoule. Only a small fraction of this energy is required for acceleration, the largest part is dissipated in friction in the wirespring guiding. A disadvantage of an electromagnetic system as described above is the low efficiency of the conversion of electrical energy into mechanical work when the system airgap is large. This is due to the large amount of magnetic strayfields in this situation. This means that a fast working system has to be made by applying a rather large current through the coil of the magnet when the airgap is large. When the armature has reached its endposition the value of the current may drop to a lower level, the "holding" current, because in this position the airgap is closed and the system efficiency is better. The form of the current as a function of time is sketched in Fig. 19.

The maximum value of the current that is reached in this way of switching might easily be ten times as high as the current during "holding".

The "dip" is caused by the sudden change in induction when the armature reaches the core and the magnetic circuit is closed. The poor efficiency of the system (in the order of about 5%) necessitates the installation of a larger power-supply, switching transistors for a larger current-rating and a higher mean operating temperature for the electromagnets.

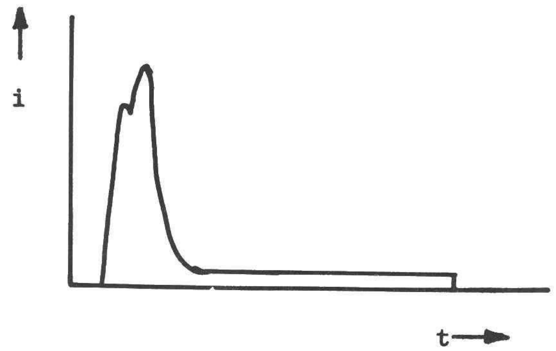

FIGURE 19

Current versus time for the system from Fig. 18.

Another fact that is worth mentioning here is the rather uncontrolled movement of the armature: in reality it is accelerated over the complete stroke until it hits the core and suddenly comes to a stop. Experience has proved that this sudden deceleration causes considerable stresses in the connections (springwire and two glue joints) between armature and selection-block.

To prevent the above mentioned disadvantages of the electromagnetic selection-system the system is a little modified. Because forty selection systems are present an elegant solution is possible, while the cost of the additional hardware can be divided among forty systems.

The solution consists of an extra beam that controls the movements of all forty armatures and that is driven from the already available shaft on which the cam for the duplex-movement is fitted (Fig. 20).

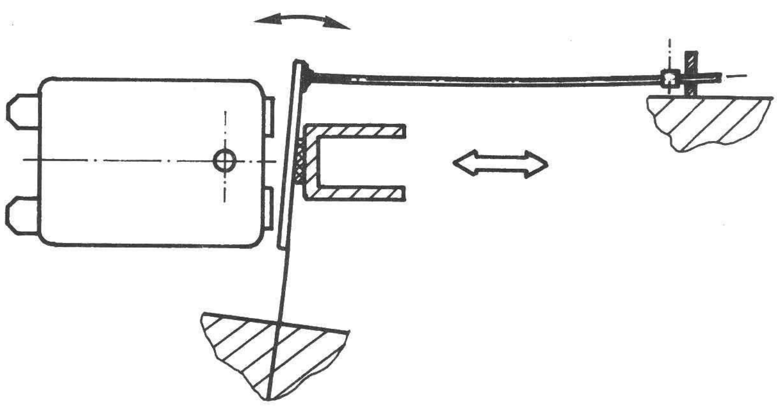

FIGURE 20

Selection system with controlled armature movement.

This assures the correct synchronisation with the timing of the duplex-movement. The principle of operation is that all forty armatures are moved towards the electromagnets during each brailling cycle. In this way the armatures can approach the electromagnets with a speed that is decreasing till zero. When the airgap is at its smallest value, those magnets that are to select their brailling pin are switched on. After this the "pushing" beam is retracted and the not-selected armatures move back again. In this way one only has to supply the relatively small "holding" current and both movements of all armatures, there and back, can be completely controlled, because the selected magnets remain switched on till the next brailling cycle when the pushing beam is returned to the left-most position (Fig. 20) and the switching pattern is changed for the next brailling cycle. If a magnet is not switched on, the corresponding armature keeps following the movements of the pushing beam because all leafsprings carrying the armatures are pre-loaded in this direction. The energy that is required to move the armatures in both directions does not have to be supplied by the magnets itself (with their inherently low efficiency) but can be supplied by the main motor which has a much better efficiency. (The efficiency of electromagnets during their work stroke has been reported to be around 10% compared to the efficiency of an electric motor of about 58%.) (Ref. 9 and 10.)

4.4. Description of the selection system.

Drawing 8.1.2 is a cross-section through the sub-assembly that contains the duplex system and the forty "selection" systems. All units are positioned between two aluminium sideplates (partnrs 138) that are kept on a certain distance from each other by two aluminium beams (partnrs 43 and 98). Forty electromagnets (partnrs 83) are clamped between two beams (partnrs 75 and 85) that are attached to both sideplates. The electromagnets are pushed in from the bottom, until they hit the steel beams (partnr 77), that are connected to the beams 75 and 85, then the set screw 76 is tightened, so all cores of the electromagnets end in one plane. To prevent excessive deformation of the parts 75 and 85 when tightening these forty screws, a thin steel plate is added that connects the top surfaces of these beams with each other over the complete length of the beams. When all forty magnets have been assembled, a steel pin is put through the circular holes of all magnets as an extra positioning device.
The (steel) camshaft (partnr 41) contains two radial cams (partnrs 40) and

one axial cam (not shown on this drawing). The two radial cams drive the "pushing" beam (partnr 79) up and down over a 2 mm stroke by means of the two followers (partnrs 80) that are attached to the pushing beam by the 2 blocks 45. (These cams were calculated with the aid of a "cam-follower" design routine that was developed within the section "Production Automation" of the mechanical engineering department of the Delft University.)
These blocks also serve to clamp four leafsprings (partnrs 96) that guide the pushing beam during its movement.
Two helical springs (partnrs 46) keep followers and cams in contact. The axial cam on the camshaft 41 drives (again using a spring loaded follower) the duplex beam 33; this movement has a stroke of 2.4 mm and is directed perpendicular to the plane of the cross-section. The duplex beam too has a parallel leaf spring guiding (partnrs 39).
Using the small etched strip 32 the selection blocks follow the movement of the duplex beam. The duplex beam performs one complete movement during each revolution of the camshaft; the pushing beam performs two complete strokes during each revolution.

The wire springs 74 connect the selection blocks 31 to their armatures 78 which are glued to the leaf springs 151 by means of small rubber blocks. The purpose of these rubber blocks is to enable a small rotation of the (soft iron) armatures to align with the pole pieces of the cores of the electromagnets, without deformation of leaf spring 84. A coarse adjustment (and similar for all armatures) can be made by changing the position of the clamping beam 90. This beam can rotate about pins 88 to set the degree of preload on leaf springs and armatures, but the position of pins 88 is adjustable as well, because they are fitted in the sideplates by means of eccentric bushings. The location of the position of pins 88 relative to the clamping point of the leafsprings 84 is chosen at one third of the leaf-spring length: the virtual point of rotation when the leafspring is bending to follow the movements of the pushing beam. In this way a change in the amount of preload (a rotation about pins 88) does not influence the position of the armatures in the vertical or horizontal direction.
The camshaft (partnr 41) is supported in both sideplates using two ball-bearings in bushings that have an eccentric bore (partnrs 108). A rotation of these bushings changes the position of the stroke of the pushing beam (79), so controlling the right contact between armatures and electromagnets in the lowest position of the pushing beam. The complete selection sub-assembly is fitted against the fixed beam 47 (from the brailling frame) by

bolts, assuring the correct position of the selection blocks above the surface of beam 47. The braille forming sub-assembly (brailling beam and pins) is bolted against the left side of the sideplates 138, which enables an alignment of the relative positions of pins and selectionblocks.

5. THE PAPERTRANSPORT SYSTEM.

5.1. Specifications.

With the principle of brailling that was described earlier, there is a need for a papertransport system, that is able to move the paper at moments that can be externally controlled over discrete distances of two different sizes. The papermovement may not be continuously coupled to the main shaft because it should be possible to have the main shaft running and the paper standing still. If this is possible, some flywheel-action can be added to store kinetic energy and give the printer a more constant braillingcycle. Two different stepsizes are needed if the system should transport the paper over the distance between dots 3-6 and 1-4 (5mm) in one operation. If this is accomplished the output of the printer is maximized. Because of the continuously running main shaft the brailling beam is continuously moving as well, so the available time for papertransport is limited. If the paper has to be transported it can only be done when the brailling beam is in such a position that there is enough clearance at both sides of the (brailled) paper. If the brailling beam is moved with two eccentricly mounted rollers, as described in Chapter 3.1, the movement of this beam as a function of time is represented as a sine-function. If the amplitude of this movement is 4 mm and the cycletime is 33 ms, the available time for papertransport can be deduced if the necessary clearances are known.
The value of 4 mm was chosen as a compromise between larger values that result in larger speeds of the brailling beam when its hits the paper, producing more noise and unbalance, and smaller strokes which limit the available paper transport time.

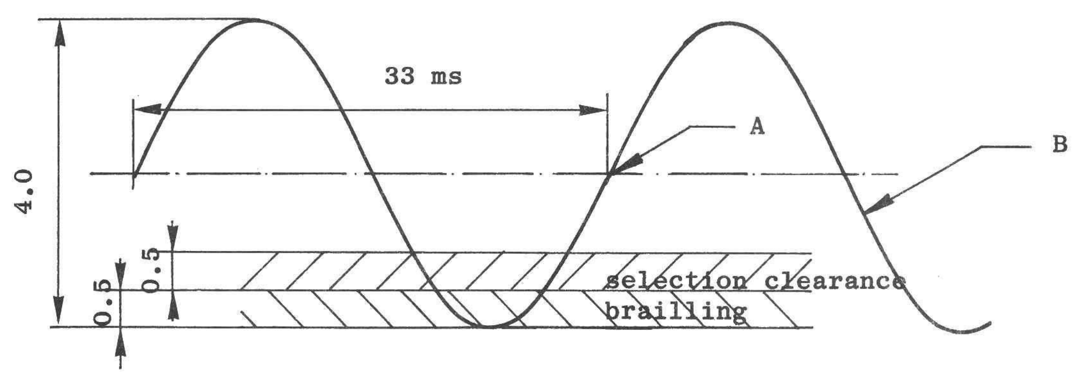

FIGURE 21
Displacement of the brailling beam versus time.

If the movement of the brailling beam is described starting at its lowest point, the first 0.5 mm of its movement is taken for the restoration of the clearance between selectionblocks and brailling pins. The next 1.0 mm is necessary to free the paper from both brailling pins and brailling holes (Fig. 22).

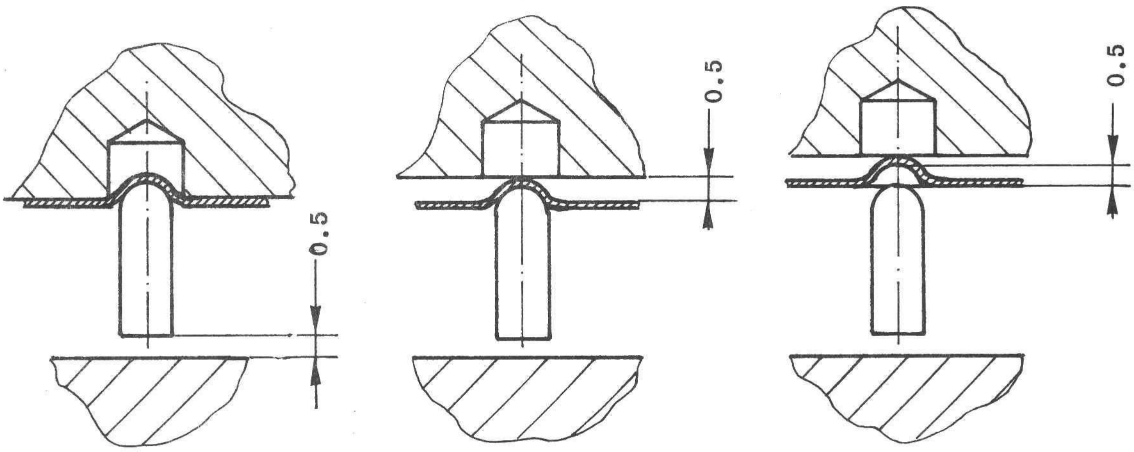

FIGURE 22

Three phases from the brailling process.

If the minimum clearance, necessary at both sides of the paper before the papertransport can begin, is set to 0.25 mm, this means that papertransport can start when the brailling beam has travelled 2 mm upwards from its lowest position. This point is marked as point A in Fig. 21. If the same minimum clearance is taken at the end of the papermovement (point B in Fig. 21) the available time for papertransport can be calculated to be 18 ms. In this time the total movement (in the "worst" case 5 mm) should be completed.

Another decision that should be made is the choice of the form of the paper. It is possible to get paper in braille quality on large rolls (width 250 mm, diameter of the roll 450 mm) or in fanfold form. In the last form the paper contains holes at the sides to enable a sprocket- or tractor-mechanism to hold the paper. Because the fanfold paper is by far the most convenient form for the user this type is chosen. (The handling of a roll of paper of the size stated above by one person is hardly possible because its mass is about 25 kg.) The last point that has to be mentioned here is the direction of the papertransport movement. Normally the direction is such that a braille line is built up by brailling the sequence 1-4-2-5-3-6. In this fashion the papertransport direction causes the paper to appear at the top of the lineprinter. It is put in at the bottom of the printer, where the paper is pulled from a box. Immediately after the place where the brailling takes place, the paper is bent backwards, away from the user (when the equipment is used as a terminal), so the brailled pages can be collected in a box behind the printer. Although care has been taken to present the brailled line as soon as possible after it is brailled, at a comfortable angle to be read, the last brailled line is not at an angle so that it can be read as such. Therefore, if there is no action on the printer for a period of one second, the paper is transported in the normal brailling direction for two more line distances. This takes about 135 ms. At this position the last line can easily be read. When the next line is to be printed the paper is moved in the reverse direction over 22.5 mm and then 2.5 mm in the normal brailling direction. This last step is done to restore all backlash at the same side as it used to be, and put the paper in exactly the same position it had immediately after brailling the last line. At this point the brailling of the next line is started.

5.2. Possible concepts.

Starting from the paper itself and working towards the beginning of the transportchain a tractordrive-system is chosen. This is because these systems divide the force that is necessary to move the paper over a large number of pins without the necessity for a large space, which would be the case when using sprockets. The papertractors can take the paper at any place where the paper is flat over a length that is sufficient and there is no need to design the paperway such that it contains a radius that fits the radius of the papersprocket. In this design a tractor-assembly is used that is supplied by Digital Equipment Corporation. The effective radius of these tractors is 9.5 mm, so for a step of 2.5 mm the tractorshaft has to move 0.26 radian. The moment of inertia of the tractorassembly was measured to be $1 * 10^{-5}$ kgm^2 (Ref. 11).

As (mechanical) powersupply for the papertransportsystem three possibilities exist which are feasible at first glance:

- an electric servomotor;
- an electric steppermotor;
- a mechanical coupling with the main electric motor that drives the brailling beam.

To start with the last item: A mechanical coupling with the continuously running main shaft that enables two different step sizes of the paper in two directions and synchronized with the movement of the brailling beam, which on top of this has to be switchable sounds like a rather complicated mechanism. Furthermore these mechanical switching elements usually show a certain amount of wear that tends to influence their performance on the long run. Because of this the last possibility is dropped. When comparing electric servomotors and electric steppermotors the steppermotors are usually the cheapest solution when the total system is considered and is characterised as "position-controlled". When a "speed-controlled" system is considered (the speed is the most important aspect of the output) the servomotor might be the best solution. Because the most important aspect here is the accuracy with which the steps are made, a steppermotor is preferred. To make sure that this was the most economic solution, besides a system employing an electric steppermotor that was designed and built, a system with an electric servomotor was evaluated, but for the specific requirements in this case, this system proved to be at least twice as expensive.

5.3. The steppermotor system.

As steppermotor a "BERGER RDM 569/50" motor was chosen, which proved to be the cheapest solution for this purpose. The investigation included the price of the driver electronics that are necessary with each motor to obtain the predicted performance curves. The step angle of this motor is 0.72 degrees (500 steps per revolution), the adaptation to the required step angle of 0.26 radian at the papertractor-shaft is accomplished by the use of a timing belt and multiple motorsteps for each papermovement. This timing belt offers the opportunity to match the inertia of the rotor of the steppermotor with the inertia of the load as it is "seen" by the motor at the steppermotor-shaft. The influence of the load inertia is reduced or amplified with the square of the speed ratio, depending on whether the drive is decelerating or accelerating. The timing belt also offers a certain amount of damping at a relatively small compliance (Ref. 12).
In applications where the operation of the steppermotor consists for the largest part of acceleration and deceleration of the load, the minimum response time is obtained for low inductance motors, when the inertias of motor and load (at the motorshaft) are the same. Here the inertia of the total papertransport assembly (tractors, shafts and paper) amounts to $1*10^{-5}$ kgm^2, and the rotor inertia is $4*10^{-5}$ kgm^2. If a speed ratio is chosen of

2.1 (accelerating) the nominal step of 2.5 mm is reached within 0.3% when 10 motorsteps are taken. The load inertia as seen by the motor is $2.1^2 \times 1 \times 10^{-5} = 4.41 \cdot 10^{-5}$ kgm^2, which is about the same as the rotor inertia. If the papertractor-shaft has to move 0.52 radian (5 mm operation) the starting torque of the motor can be calculated if an assumption is made for the value of the acceleration as a function of time. If it is assumed that the motor can exert a torque as a function of time, as sketched in Fig. 23 the total movement can be calculated.

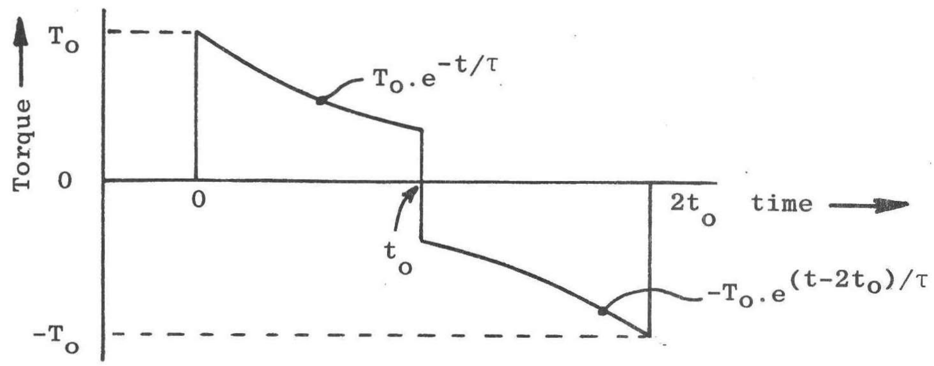

FIGURE 23

Torque of the papertransport stepper motor versus time.

This assumption leads to a torque as function of the motor speed that agrees quite well with the motor characteristic (see App. 8.7).
Applying the calculation method from App. 8.7 the Berger "RDM 569/50" can make the large step (5 mm paper movement) in approximately 12 ms, well within the 18 ms that are available.

6. THE ELECTRONIC CONTROL SYSTEM.

6.1. Specification of control functions.

At this point the specifications will be assembled of the functions that the control system has to perform. A FACIT 4020 tapereader can supply the data to be printed at a sufficient rate, but the handshaking that goes with this datatransfer has to be initialized by some external device. This is the first function that the control system has to perform: operate as data-acceptor in a FACIT SP 1 interface. From the tapereader the characters are transmitted in serial form, while the lineprinter can only print the line when all characters on that line are known. So the second function is to operate as a data-buffer. When the reading of the papertape is started for the first time, the tape is advanced until the first "End of line"-character is encountered. All printable characters before this first EOL-character are ignored. Brailling starts with the first line after this EOL-character. This implies that the first line on each tape must be preceded by an EOL-symbol. This has the advantage that, when one wants to start printing in the middle of a tape, it is not necessary to position the tape exactly with the first character of the first line to be printed in the reading position. It is sufficient to position the reading position of the reader somewhere in the previous line. This is a simple procedure.

When the characters are read into the data-buffer, each character is counted and when less than forty characters are read for one line, the rest of the line is filled with space characters. If an attempt is made to print more than forty characters on one line, the reading is stopped and an error-condition is signalled. After the complete line is read the brailling can start. For this purpose the contents of the data-buffer that has just been filled (the "read" buffer) are transfered to another data-buffer (the "print" buffer) that is also forty characters large, and while the contents of the print-buffer are brailled the read-buffer is filled with the characters of the next line. This simultaneous brailling and reading is done because the maximum reading speed of the papertapereader is 300 characters per second, so the reading of the maximum line-length of 40 characters takes 133 ms. If reading the next line is postponed till the previous line is brailled the total cycle would take 333 ms. Now the time to read a line and braille the previous line is 200 ms.

The controlsystem decides which magnets should be switched on in the first brailling cycle and synchronizes this with the angular position of the main shaft and the position of the duplex-beam. The same holds for the next brailling cycle. Then the pulsetrain for the papertransport steppermotor is started, again with its first pulse synchronized with the position of the main shaft to ensure the correct minimum clearances at the start of the papermovement. By supplying the correct number of pulses the paper is moved 2.5 mm. The brailledots 2, 4, 3 and 6 are brailled in the same way. After brailling dots 6, the paper is moved over 5 mm by supplying the double number of pulses to the steppermotor and the complete sequence can be repeated for the next line. The control system assumes that paper is used that has perforations at 12" distances, so that 30 lines can be printed on one page.
There are two features added to assist the operator in positioning the paper. The first is the "single line" button. When depressed the printer advances the paper over one linedistance. The second feature is the "top of form" button. This function transports the paper till the beginning of the next page is in the printing position. This can be comfortable when the user wants to start new output (for instance from a new papertape) on a new page. Something that will aid in troubleshooting is the incorporation of a "test" button. This button is not on the frontpanel of the printer but can only be reached ater opening the cover of the electronics. Activation of this button will cause the printer to braille one complete page. For this purpose no external information input is necessary because an internally generated testpattern of 4 braillelines is printed and this pattern is repeated 7 times on the page. The pattern was chosen to enable a fast diagnosis of possible printer failures. In this manner the printer can be tested without using any external input medium.
All push buttons can be activated at all times but the appropriate printer action will only follow, when at the moment of activation the printer is not printing or transporting paper, otherwise the activation of buttons is ignored.
Another feature that was added to facilitate the use of the printer in a terminal set-up (and to a smaller extent when used as a stand-alone printer) is the automatic positioning of the paper in the reading position when there has been no printer action for 1 second. If this happens, the paper is automatically advanced 2 line-distances to bring the last line in a position in which it can easily be read. When there is new action of the printer, the paper is restored first in its former position, and the brailling of the next line starts.

6.2. The control hardware.

To perform the control functions that were mentioned in the previous chapter an Intel SBC 80/10 unit was chosen (Single Board Computer 80/10). The SBC 80/10 is a complete computer system on a single 7 by 12 inch printed circuit card for OEM applications. This system was chosen because it is based on the Intel 8080A microprocessor (the "T-Ford" among the 8-bits microprocessors), that is frequently used in both the department of Electrical Engineering and the department of Physics of the Delft University of Technology, so that software support was possible there. An introduction to microprocessor applications in general is given by Altman and Scrupski (Ref. 16), while Weller and Shatzel (Ref. 17) deal more specificly with the Intel 8080, also in real-time applications.
For program development the development system (Intel MDS) of the department of Physics could be used. The SBC 80/10 contains 1 K 8-bit words of Random Access memory (RAM) and sockets for up to 4 K of non volatile Read-Only memory (ROM) that may be added in 1K increments. The 80/10 contains 48 programmable Input/Output lines and a programmable serial communications interface. Mode of operation (synchronous or asynchronous), data format, control character format, parity and transmission rate are all under program control. The SBC 80/10 also includes jumper selectable teletype or RS 232 C compatible interfaces, which facilitate the interfacing of the lineprinter when operating as a terminal. Also a single-level interrupt capability is provided.
Because the SBC 80/10-board alone does not offer enough I/0-lines to support the lineprinter, an expansion board was added to the system and the SBC 80/10 was bought as part of a SBC 80P prototyping package. This package already contains an expansion board and a SBC 604 cardcage and backplane, together with a system monitor, that is very helpfull in the prototype stage.
A description of the SBC 80/10 hardware can be found in the "SBC 80/10 Hardware Reference Manual" (Ref. 13). The hardware that was added on the expansion board will be described here. All components that were added can be found in the Appendix on schematic 8.2.1. The three most important additions are the parts in the center of this schematic with the "Intel" type numbers 8259, 8253 and 8255.
The 8255-chip provides a programmable peripheral interface, containing three 8-bits ports which add 24 I/0-lines to the already available 48 lines.
The 8253-chip is described as a programmable interval timer, containing three independent 16-bits counters. This 8253 can generate accurate time

delays under software control. Each of the counters of the 8253 can be programmed with the desired quantity, then upon command the 8253 will count out the delay and interrupt the processor when the programmed time has elapsed. So there is no need for timing loops in software and multiple delays are easily maintained. The output of each timer is connected with one input of the 8259, which is a programmable interrupt controller. This interrupt controller is able to resolve priority among eight different interrupt sources, where the standard SBC 80/10 recognizes only one interrupt level. The 8259 resolves priority among all eight possible interrupt inputs, according to an algorithm which is programmable by the user. The 3205-chip decodes six lines from the address bus to provide "chip select" signals for all three devices mentioned, once their specific address appears on the address bus. The frequency of the "Constant Clock" signal that is available on the system bus (pin 31) is divided by 1000 in 3 "7490" elements to supply a constant frequency with a period of 108 µsec as clock signal for the three 8253 timers.

The six sockets on the extreme right of the schematic are filled with either "SBC 902"-elements (a resistor network) when it concerns input lines, or "7437" chips (linedrivers) when output lines are concerned. The two 8226 devices are bidirectional bus drivers, used as a buffer between the system data bus and the components on the expansion board.

The addition of the 8259 necessitated a change on the original 80/10 board. Originally when an interrupt is acknowledged by the 8080 microprocessor, the program alway jumps to the same memory address. With the 8259, the jump depends on which 8259-interrupt input received the interrupt request. The address to which the program should jump is inserted by a normal "call" instruction, that is generated by the 8259. To make sure that this "call" instruction reaches the microprocessor, a change was necessary in the control circuit for the 8226 bus drivers on the 80/10 board. The direction of the data flow in these drivers is changed when the INTA/-pulse is generated. (This means an interrupt request has been acknowledged by the microprocessor.)

The timing signals for the processor emanate from two "interrupter assemblies" (LED-photodarlington combinations) that are mounted on the printer and triggered by a timing disc on the main shaft of the printer. The timing disc contains holes in certain positions and the passing of each hole produces an interrupt request for the 8259 chip. Another interrupter assembly is mounted in such a way that it can discriminate whether the duplex-beam is in the left or the right position.

A microswitch in the paper track is used to detect if paper is present in

the printer or not.
In the prototype all error conditions are signalled to the user by light emitting diodes. Eventually these LED's of course have to be changed for an accoustic or tactile signal source to accommodate the blind user.
The papertransport steppermotor is driven from a printed circuit board supplied by the manufacturer of the steppermotor. For our purpose this PCB (besides of course the power supply) only needs two signals: steppulse and stepping direction. The main electric motor is connected to the mains supply by a relay that is controlled by a microprocessor output line. This enables the microprocessor to switch the main motor off when there has been no action on the printer for about one second.
The forty selection magnets are driven by forty output lines that control forty switching transistors. These magnets have a separate powersupply.
Summarizing, the I/O-lines of the control system are used as follows:

Input:	Function	Number of lines
	Data from reader	8
	Control from reader	2
	Synchronization pulses from printer	3
	Paper detection	1
	Function selection push button	4
	"Not used"	2
		— +
	Total	20

Output:	Function	Number of lines
	Control to reader	3
	Status indication (LED's)	4
	Steppermotor control	2
	Main motor control	1
	Selection magnets	40
	"Not used"	2
		— +
	Total	52

6.3. The control software*).

The structure of the control program in its simplest form can be observed in the flow charts from Appendix 8.3

6.3.1 Initialization sequence.

After the "reset" is given (the system features both manual and an automatic reset two seconds after the power has been switched on), the program goes into the initialization sequence (flow chart 1, left), that starts by blocking all interrupts. Hereafter all three timers are programmed to operate in the desired mode, that means they should interrupt the processor when terminal count is reached. At this moment the counter output will go high and produce an interrupt request signal. This output remains high until the selected count register is reloaded or until the mode is set again. Reloading the count register during counting will restart the procecure, the counter output remaining low. After programming the timers, all nine eightbit I/0-ports are programmed to operate in the right mode. Three operational modes can be selected: basic I/0, strobed I/0 or bi-directional bus. Here all ports are programmed in the first mode, where the output lines are latched and inputs are not latched.
The "8259" Interrupt Controller can operate in four different modes: fully nested, rotating priority, specific priority or polled mode. It is programmed to operate in the fully nested mode, which means that all interrupt request lines are assigned specific priorities ranging from zero to seven. When an interrupt is acknowledged, interrupts of lower priority are inhibited, until all interrupts with higher priority are serviced.
After the mode setting all interrupts are enabled and the processor starts monitoring the variable PRSTA (Printer status) to see whether the printer is ready to start. If no action follows the program stays in a loop directly after "ready", meanwhile servicing all interrupts that are coming.
Interrupts emanate from the following sources:

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*) *Note: The software that is described here, has actually run on a prototype of the lineprinter that was built in the Finemechanical Workshop of the Delft University of Technology. Therefore it contains minor differences from the program that is necessary in the final design, for instance in the number of pulses necessary to drive the papertransport stepper motor (8 instead of 10).*

every pushbutton activation (1x);
synchronization pulses (2x);
all timers (3x).

(Two interrupt request lines remain unused.)
In this waiting stage the variable PRSTA has the value zero. Activation of any of the four pushbuttons (Tape, Test, Top of Form, Single Line) sets PRSTA to a different value and when the switch-interrupt is serviced the processor jumps to a routine corresponding to the button that was pressed. The action following a pushbutton activation is indicated on flow chart 1 too. If PRSTA is one or four the activation of the pushbutton that caused the interrupt is ignored. This corresponds to situations in which the printer is performing an operation and cannot yet be programmed for the next operation. PRSTA=1 is the condition during normal running, PRSTA=4 occurs when the printer was stopped because it ran out of paper.
When new·commands may be accepted, the processor scans all pushbuttons to detect which one caused the interrupt. This information is stored in the variable "Switch Status", for future use by the main program. Then the processor checks if there is paper available. If this condition is full-filled timer 1 is started to count down a delay of four seconds. When timer 1 has been loaded, all status indication LED's are cleared and the main motor is started. After this the switch interrupt routine is completed.

During the four seconds timer 1 needs to count down, the main motor has the opportunity to reach its nominal speed. When the interrupt comes from timer 1 the following happens (flow chart 1, right): When timer 1 expires after a first start or a restart (PRSTA=ϕ or 3), all interrupts are disabled and the processor waits till the pulse from diode 1 arrives. This pulse occurs once during every revolution of the main printer shaft. At this moment the variable "DIO 2" is assigned the value zero, to make it possible to discriminate between the two different pulses per main shaft revolution that appear on the line from diode 2. (See App. 8.4.)
Then timer 1 is reloaded to count down a 4 seconds delay, and all interrupts are enabled again. From this moment on, no more interrupt disabling may occur, otherwise the correct discrimination between the two different "DIO 2" pulses might be lost.
PRSTA is assigned the value 1 and the interrupt routine from timer 1 is completed. During normal running timer 1 is reloaded every time a paper-transport occurs, so normally it will never produce another interrupt. Only when there is no action on the printer for four seconds (for whatever reason)

the timer produces an interrupt. Depending on the situation the main motor is switched off then, with or without transporting the paper over two line-distances to bring the last line in the reading position. When a restart occurs, timer 1 is used again to allow the main motor to reach its nominal speed before synchronizing. When the control system is synchronized the paper is restored in the printing position and the interrupt service routine of timer 1 is completed. When control is returned to the main program, PRSTA has been set to 1 and a jump occurs to the program segment that will perform the operation that was started by pushing a button.

6.3.2 Normal brailling.

Flow charts 3 and 4 describe the events that occur after the "TAPE"-button has been depressed. The processor starts by setting the variable CHCNT (Character Counter) to zero. Then the processor checks for paper presence. If PRSTA is still 1, the handshaking with the papertape reader is initiated by checking if the reader is ready.
If this is confirmed, a "read one character"-command is sent to the reader. If this data is transmitted to the processor the reader is put at rest and the character is processed. If all channels on the tape were zero or one, the next character on the tape is read. This means the printer accepts papertapes with both leading zeros or ones ("delete"). In this way the "leader" of the tape is transported until printable information is encountered. When the character that is read, is a braille character or a space character, the character counter is checked to see whether it is already forty or not. If this is not so, the character is stored in the read-buffer (this buffer can contain 40 characters) and the character counter is incremented by one. Then the processor returns to "START" to read the next character. If the tape contains more than forty characters on one line, the main motor is stopped and the "FORMAT ERROR"-LED is lit.
If the character that is read is neither a braille symbol nor a space, it is checked whether it is an "End of Line"-character. If it is the first EOL that is read after the "TAPE" button was depressed, the complete read-buffer is cleared, the character counter is put to zero again and the next character is read. If the EOL-symbol was not the first one, the processor waits at this point till the previous line is completely printed. Then the information from the read-buffer is transfered to the print-buffer. The read-buffer is cleared, the character counter set to zero and the variable PRBRE (Print-buffer ready) gets the value one. This is to indicate that the print-buffer has been filled with the next line and that printing may commence. While the

contents of the print-buffer are being printed, the read-buffer is already filled with the next line.

If the control character that was read, was no EOL-symbol, it could have been an EOP-symbol (End of Page). If this is the case, after waiting until the previous line is printed, the paper is transported till the top of the next page is in the printing position. The character counter is set to zero and the processor is ready to read the next frame. If the processor reads a character which it does not recognize, the reading of the tape is stopped at that point and the printer motor is stopped as well.

The actual printing of the characters that are now in the print-buffer starts on the pulses from diode 2, once PRBRE received the value 1, and is described on flow chart 5. When diode 2 produces an interrupt (twice during each print shaft revolution) the value of the variable "DIO 2" is checked to determine whether it concerns the first or the second pulse during the print cycle. On one of the two, the position of the duplex beam is checked; on the other the switching pattern of the forty selection magnets is changed. If DIO 2 is zero, the duplex-beam position should be checked. If the print-buffer contents are ready to be printed (PRBRE=1), PRBRE is set to two to indicate that the printing has started and PCYC (Print cycle) is assigned the value 1 to keep track of the number of print cycles that have been performed since printing of the new line started. At this moment already the contents of the printbuffer are scanned to see which selection magnets should be switched on when the next pulse from diode 2 arrives. This information is stored in five memory bytes (MAPO=magnet position) to have the switching pattern immediately available. This is done here, because this is a rather time consuming process and the magnets should be switched immediately after the pulse from diode 2. (Under worst case conditions the assembly of these five output bytes takes about 8 ms.)

By means of diode 3 the position of the duplex-beam is checked and recorded by variable DUL (Duplex Left). This completes this routine in the case where DIO 2 was 1 (first pulse). On the next pulse from diode 2 (DIO 2 is zero then) the selection magnets are switched. If PCYC is zero (the normal case when the printer is not printing) all selection magnets are switched off. When PCYC has the value 1, the processor checks whether the duplex-beam was left or right during the previous position control. If it was left during the previous printing cycle (DUL=1), it is now on the righthand side and all magnets are left switched off. If the duplex-beam was right (DUL=ϕ), it is now left and printing may start. The selection magnets are switched according to the pattern stored in MAPO and PCYC is set to two. The print-

buffer is scanned again here to fill MAPO with five new output bytes containing the information for the printing of dots 4 from all characters on this line. This completes this interrupt service routine.
The process is essentially the same for all six printing cycles that are necessary to print the complete line: First a position check on the duplex-beam, then the switching of the selection magnets and finally the assembly of the new switching pattern, to be used in the next cycle. The first printing cycle may start with the duplex-beam in the wrong (righthand) position; the processor then waits one print-shaft revolution and printing starts with the duplex-beam in the lefthand position. During following printing cycles however, the duplex-beam position is checked again, but if it is now in the wrong position, this is caused by either a mechanical or an electronic failure. The printer motor is stopped then, all magnets are switched off to prevent further erroneous printing and the "PRINTER ERROR"-LED is lit.

6.3.3 Papertransport.

After printing dots 4, 5 and 6 the printing cycle is followed by papertransport. This is accomplished by introduction of the variables TP 4 and TP 8 (Transport Pulse). TP 4 is set to four after printing dots 4 and 5, while TP 8 is set to eight after brailling dot 6. (At this moment PRBRE is set to three to indicate that the contents of the print-buffer have been printed and the linecounter is incremented by one.)

The variables TP 4 and TP 8 are processed when diode 1 produces an interrupt pulse, once during every print-shaft revolution. If TP 4 is four or TP 8 is eight, papertransport is started at this moment. Otherwise no action is taken (Flow chart 6). Timer ϕ is started to count down the delay till the second pulse to the steppermotor should be sent out (resp. 1.9 and 1.5 ms), and the direction bit is set according to the value of PRSTA. (This decides whether papertransport should take place in the normal (forward) direction or in the reverse direction). Step pulse line and direction line are set at the same moment and timer 2 is programmed to produce a delay of 500 μs. This is necessary to reset the step pulse line because all output lines are latched. This completes the diode 1 interrupt routine.

Flow chart 2 describes the part of the program that is executed when the "TEST" button is depressed. First the linecounter is checked to see in what position the paper is. If the first line of a new sheet is not in the printing position, the paper is transported until this is accomplished. Then one line of paper is transported without printing and a testcounter is set to seven. If enough paper is present, the first testline of a set of four testlines is transfered to the print-buffer and printed, using the normal synchronization pulses from diodes 1, 2 and 3. The same procedure takes place with the next three testlines. This pattern is repeated seven times, so twenty-eight lines are printed. After this one blank line follows and the printer is ready to accept new commands.

The program parts that are executed for a single line of papertransport or for transport till the top of the next form is in the printing position are not described in flow charts because they are relatively simple. If one line must be transported two TP 8 pulses are generated which causes the paper to be moved over a total distance of 10 mm in two steps. This takes two print shaft revolutions. For a "TOP OF FORM"-transport the actual value of the linecounter decides how many TP 8 pulses should be generated.

Flow chart 7 depicts the sequence that follows when timer ϕ produces an interrupt. When papertransport should occur, the first of the pulses to the steppermotor is generated in the diode 1 interrupt sequence (flow chart 6). From here timer ϕ is loaded for the first time. If terminal count is reached this program part produces a step pulse and the right setting of the direction bit, according to the value of PRSTA; then timer ϕ is restarted for the next interval time. The processor keeps count of all pulses by decrementing the variables TP 4 or TP 8 by one, each time a step pulse is sent to the papertransport steppermotor. In this way different interval times and pulse numbers are realized for the steps of 2.5 and 5 mm, to perform the fastest papermovement without overshoot. Timer 2 is again used to reset the step pulse line, each time 500 µs after it has been set. The optimal values of all interval times have been determined empirically. Because the variation of the load of the papertransport steppermotor is not large, such an open loop control system can be tolerated.

The complete program as described here takes about 1.5 Kbytes of Read Only Memory. According to Bursky (Ref. 20) a program of this size takes a software designer about 200 days of programming (including test and debugging).

7. THE FINAL DESIGN.

7.1. Description of the final design.

Drawing 8.1.3 gives a cross-section through the complete lineprinter including the necessary electronics. Drawing 8.1.4 gives a top view of the same assembly. In drawing 8.1.3 the sub-assemblies that were described in the chapters 3.2 (brailling system) and 4.4 (selection system) are joined inside the main lineprinter frame. This main frame (partnr 2) consists of two side-plates that are connected by means of cross-beams (partnrs 61, 86 and 95). The brailling frame is fitted to both sideplates using eight bolts and bushings (partnrs 140 and 141). The selection system is connected with the fixed beam (partnr 47) by four bolts. The main motor (partnr 57) is bolted against one of the sideplates and drives the main shaft (partnr 5) and the camshaft (partnr 41) by means of a timing belt (partnr 117) and three pulleys (partnrs 115, 116 and 120). Between rollers (partnr 4) and main shaft bearings (partnr 130) the balancing masses (partnr 131) are clamped. They are dimensioned to compensate half of the unbalance that is caused by the reciprocating mass of the brailling beam and to compensate the unbalance of the main shaft completely. So the remaining unbalance forces have half the amplitude of the original forces and a changing direction. The diameter ratio between pulleys 116 and 120 is two, so the camshaft speed is half of the speed of the main shaft. Fixed on the pulley of the camshaft is the aluminium timing disk (partnr 92) that works together with two optical switches (partnrs 10) to provide the necessary timing pulses. Both switches are mounted on the same support block (partnr 9) that is fitted against the brailling frame sideplate (partnr 3). Because the position of the main shaft and camshaft can vary relative to the position of the main motor, the tensioning device with partnrs 65, 118 and 119 was added. This enables the setting of the right timing belt tension for all possible shaft positions. Two springs (partnr 14) keep the brailling beam in contact with the two driving rollers (partnr 4). The paperguiding (partnr 81) is glued to the block with partnr 68, just the same as the switch support (partnr 63). Seven stainless steel wires are bent in a form that matches the form of paperguiding 24 and attached to beam 11 by means of seven screws. They act as paperguiding, both as a new sheet of paper is put into the printer and when the paper is moving backwards to restore the paper in its position after it has been presented with the last line readable.
The papertractor assembly is placed slightly tilted with respect to the

horizontal plane for two reasons: It presents the braille text (at least the lines that were printed last) at a comfortable angle to the user when sitting behind the equipment and secondly it reduces the papermass that has to move immedeately when a line is transported. If the angle over which the paper is bent had been 90 degrees (now it is approximately 80 degrees), the paper track would have been completely straight from the bending point (partnr 24) till the extreme right of the printer; so when the paper is accelerated for transport, this complete length of paper would have to be accelerated at the same rate. With a second bend (ten degrees when the paper reaches the top of the case) only the first part of the paper has to have a high acceleration, while in the extreme case the rest of the paper may stand still. The difference will be taken up by a change in the papertrack: The paper will move higher above the top surface of the printer housing (partnr 1). Of course the actual situation will be between these two extremes. Figure 24 describes the situation just after a line has been transported. This situation is not permanent and after some time the paper will be lying on top of the case again, because the weight of the paper that is hanging down from the printer on its right side (on drawing 8.1.3) tends to pull the paper towards the printercase.

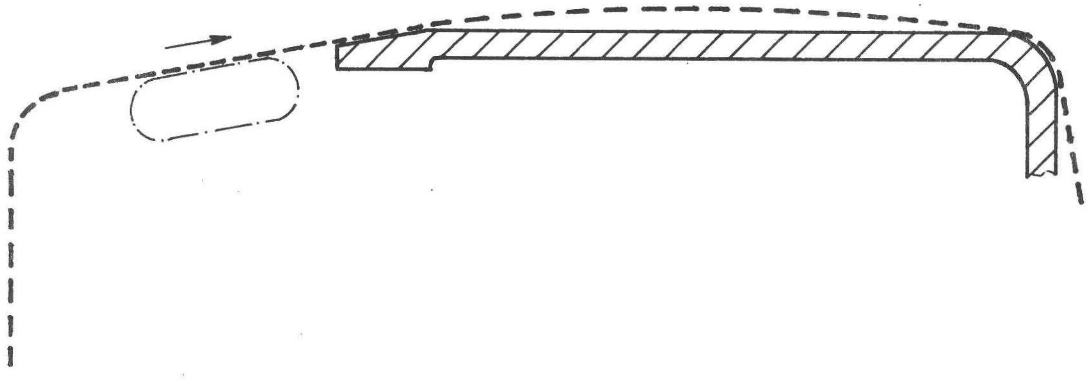


FIGURE 24

Position of paper immediately after a linefeed operation.

Each paper tractor has been equiped with a paper support plate, that extends towards the middle of the paper and that is a little bit longer than half the maximum paperwidth, so the two support plates slide over each other in the middle of the printer. The lower of the two (partnr 35) is bent down at this point and rests on the fixed beam (partnr 47) supporting both itself and the other paper support plate. This means that the minimum paperwidth that can be used on the lineprinter is a little more than half the maximum paperwidth (7.5 and 14 inches). Both tractors can be placed anywhere along the line length (of course maintaining the minimal distance of 7.5 inch to each other) so there is some freedom in the position of the text relative to the left and right paper edge.

The right hand part of the lineprinter on drawing 8.1.3 is separated from the mechanical parts by two plates that extend over the complete width of the printer (partnrs 94 and 97), and contains the necessary electronic hardware. This space is ventilated from the left hand side of the printer to the right hand side by means of a blower (partnr 54). The lower part of the electronics compartment is filled with the microprocessor cardcage, that contains the microprocessor printed circuit board and one expansion board. It provides the space for two other expansion boards. The plate 104 is formed to accommodate a data connector and attach it to a main frame side plate. The microprocessor card cage is shielded from all other components by plate 94. On top of this plate all transformers and power supplies are mounted. The paper transport steppermotor (partnr 50) is mounted against the inside of one main frame side plate and protrudes into the electronics compartment. Because the position of the papertransport drive shaft (partnr 36) is fixed there is no need for an extra device to regulate the timing belt tension. An initial adjustment of the vertical paperposition is possible (for instance when the leading sheet from a new box of paper has been brought in) by switching off the power to the steppermotor and then reaching the new positon by means of rotation of knob 124. The detent torque of the motor can still be felt when it is not energized; this shows the "preference"-positions of the steppermotor. When the steppermotor windings are energized again, the maximum angle over which the rotor moves is equal to five motorsteps (for this 5-phase steppermotor). So the deviation from the wanted position is 1.25 mm at maximum after energizing.
The lineprinter is housed in a poly-urethane foam case, that is placed over the printer from the top and secured with six screws. The case is closed with two plates (partnrs 60 and 99) that are fixed to the cover by screws. The complete printer is mounted on a frame by means of four threaded rubber blocks. This frame (not drawn) puts the printer at a comfortable height for the operator and permits paper to be fed from a box standing underneath the printer. The case has an opening at the front to accommodate a plate (partnr 58) in which switches, lights, and an acoustic signal source can be mounted.

7.2. Adjustments and disassembly.

Normally all adjustments on the selection system and on the brailling system are accomplished on these units before they are built into the lineprinter. Nevertheless some adjustments can just as well be made on the assembled printer after removal of the case:

- Correction of brailledot height by rotation of two bushes (partnrs 129) and setscrews (partnrs 128);
- The timing belt tension that goes with this new shaft position, by changing the position of bracket 65;
- The clearance between the underside of brailling pins 25 and the selection-blocks 31, by changing the position of beam 28 by means of a small rotation of the adjustment eccentrics (partnr 88) (Drawing 8.1.4);
- The amount of preload on the armatures (partnrs 78) by rotation of the clamping beam (partnr 89) around the pin 88. This adjustment is fixed by the two bolts 91;
- The position of the armatures with respect to the pole faces of the electromagnets 83, by rotation of the eccentric pins 88 (Drawing 8.1.3);
- The vertical position of the stroke of the armatures can be changed by a rotation of the eccentric bushings in which the camshaft bearings are placed;
- When the main motor has been removed the position of brailling beam and brailling pins can be adjusted with respect to the position of the selection-blocks.

When the lineprinter should be disassembled, for instance for inspection or in order to change parts, this is possible in different phases. All disassembly starts with the removal of the bottom plates and then the removal of the case. The front panel (partnr 58) remains connected to the printer. The mechanical parts of the printer can be removed as a whole or in different groups. In both cases the two main frame sideplates (partnr 2) can remain in place, connected to each other and standing on the four rubber blocks 87. Removal of all mechanical parts at once can be accomplished after taking out the main motor and taking apart all electrical connections between the mechanical parts (switches, magnets and motors) and the electronics.
When the eight bolts 140 are taken out, the bushings 141 can be removed and all mechanical groups can be taken out as a whole. Only the papertransport shafts, tractors, belt and steppermotor remain between the main frame side plates. When the pulleys from main shaft and camshaft and the main motor

are removed, together with the switch support 9, the complete assembly can be shifted 16 mm to the other side and lowered out of the main frame.

The second possibility for disassembly is taking out all parts in different groups. One such a group consists of brailling beam, brailling pins and paperguiding nr 81. This group is bolted against the two subframe sideplates (partnr 138) by using four bolts. If the main motor has been taken out, the complete subassembly can be removed in a downward direction. After this the selection subassembly can be removed, when the bolts connecting this assembly to the fixed beam (partnr 47) have been loosened. The brailling subassembly (main shaft, fixed beam and the two sideplates nr 3) can be removed last. All parts of the papertransport mechanism (steppermotor, shafts, tractors, belt and pulleys) can be removed individually.

The microprocessor cardcage has been placed in such a way that all printed circuit boards can be removed with the cage staying in the printer. With the lineprinter case removed, these boards can be drawn out to the right (on Drawing 8.1.3). All power supplies can be reached from the top (with the case removed).

7.3 Typical etched parts.

Normally the metal etching technique is applied to metal parts that are partly covered by a coating (the "resist") which selectively protects parts of the metal against the action of an acid that is sprayed against the product. In this way the covered parts remain, while the exposed parts are dissolved and washed away by the acid. By continuous spraying of acid it is possible to etch "through" a metal plate. This can give products comparable to those that are punched from sheet metal. The dimensional accuracy of the etched product can easily reach a value equal to one half of the thickness of the plate.

One way of selective covering of the sheet metal with the acid-resisting coating, is using a material that polymerises under the action of Ultra-Violet radiation. The complete product is coated with this material and is exposed to the U.V.-radiation that falls through a mask covering the complete product. After a chemical development of the coating the unexposed parts are not polymerised and can be washed away while the exposed parts form an effective covering of the sheet metal against the action of the etching acid.

The masks used during the U.V. exposure can be made with normal photographic techniques and may have rather complicated forms.
As an example of the possibilities of the metal etching technique Fig. 25 shows the masks that were used for the fabrication of the spring steel leaf springs (partnr 27) and the brailling die (partnr 28).

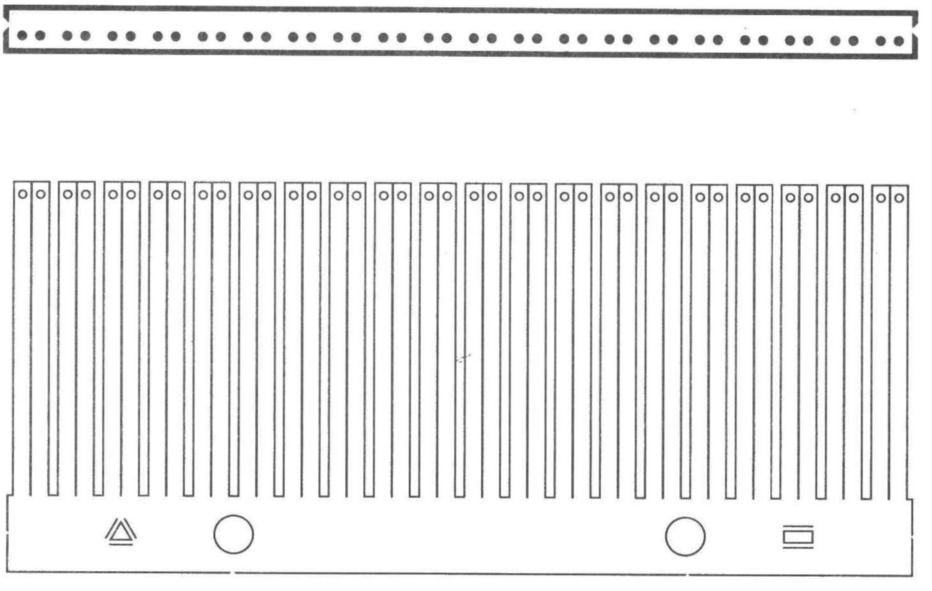


FIGURE 25
Masks that are used during the metal etching process.

The black parts on these masks show the places where the spring steel sheet will be in contact with the acid and consequently will be etched away. The circles in the leaf spring comb are necessary to let two bolts pass that connect the two steel parts that form the leaf spring clamping. The two small structures left and right of these two circles are intended to form a triangle and a rectangle with flexible sides. The size of these figures is such, that the inscribed circles that can be drawn in them, are just 0.1 mm smaller than the diameter of the positioning pins over which they are placed in the lineprinter. So there is always a negative clearance between pins and triangle resp. rectangle, that is taken up by bending of the sides of these figures. In this way it is not necessary to maintain an extreme tolerance on the size of these holes, what would be necessary in order to achieve a normal press fit. The triangle positions one point of the leaf spring comb; the rectangle prevents the rotation about this point.

The reasons for using the metal etching technique here were:

- The limited quantity of printers to be built;
- The fact that the etched product is not deformed by any forces during etching and so the endproduct is free of stresses;
- The intricate shapes of the products;
- And the flexibility the designer has during development to change the form of the product.

7.4. Practical prototype experiences.

This chapter is intended to give an impression of the kind of tests that were carried out with a laboratory prototype of the braille lineprinter and the (sometimes surprising) results of these tests. The pictures 26 and 27 were taken of the prototype with which the tests were carried out.

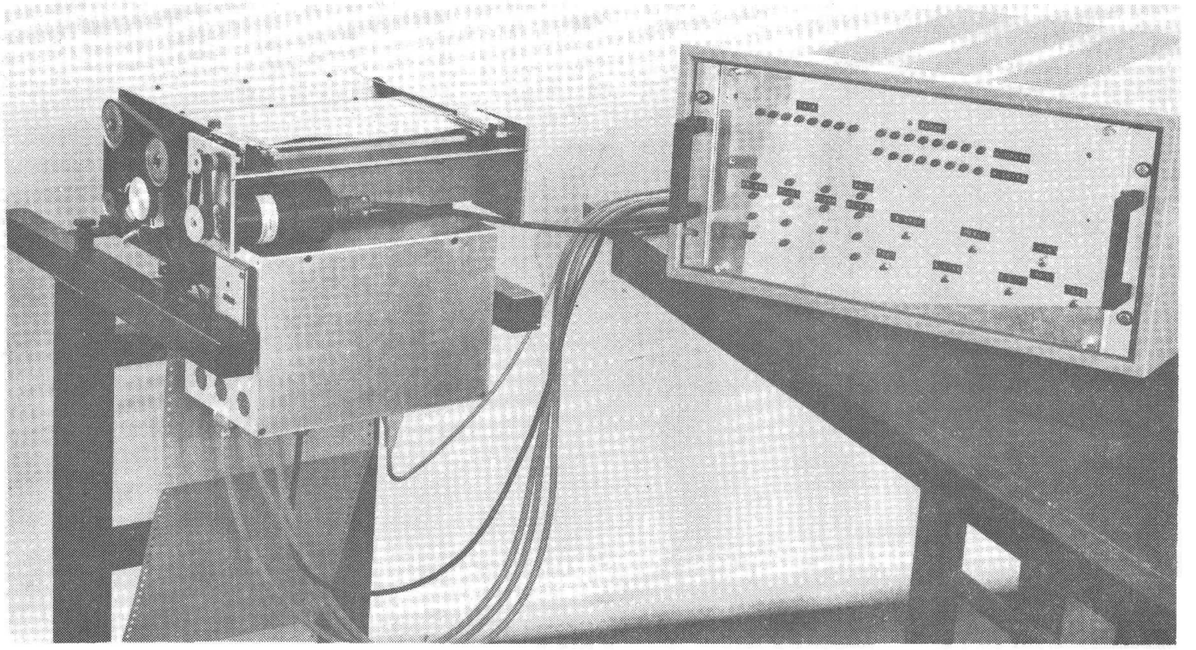


FIGURE 26

The laboratory prototype of the lineprinter.

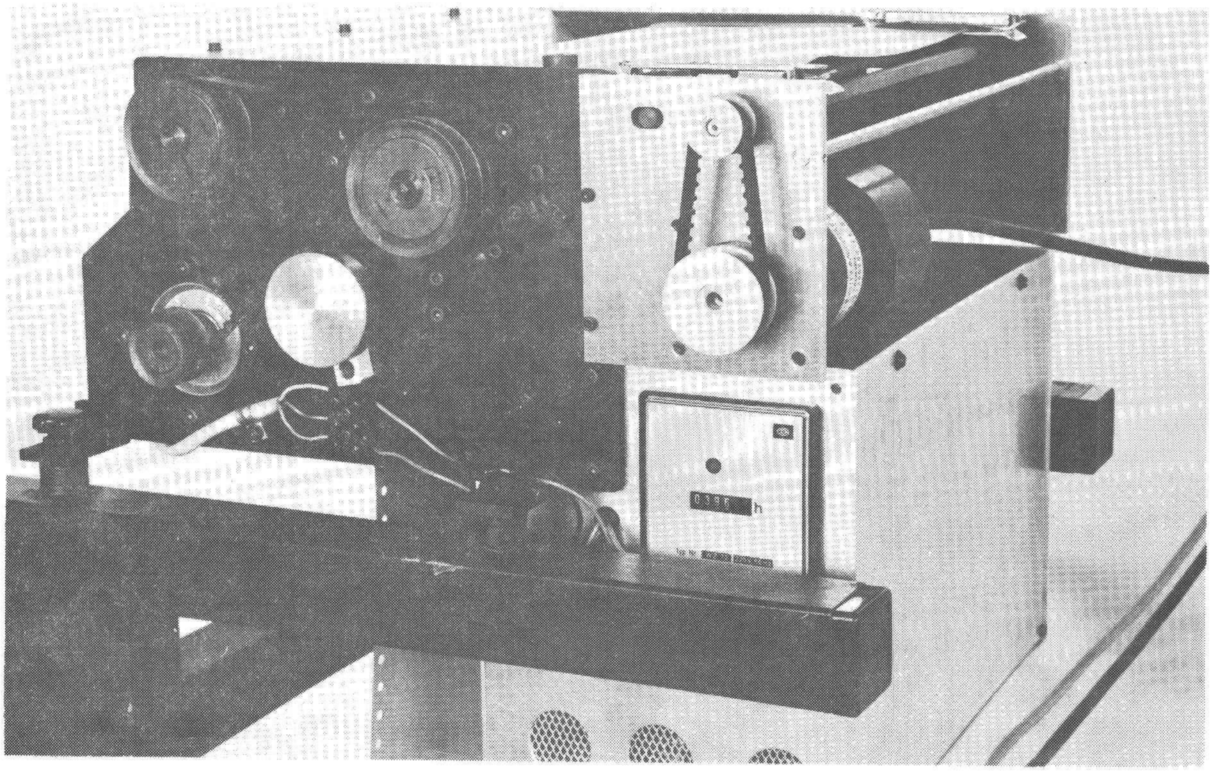


FIGURE 27

The laboratory prototype of the lineprinter.

7.4.1 Mis-alignment tests.

One of the first tests that were planned, was the one in which the brailling beam was mis-aligned on purpose with respect to the position of the brailling pins. This was done in order to verify the influence on both the braille dot quality and on the bearing systems of brailling beam and brailling pins. The tests were carried out with the brailling beam slightly off-set with respect to the brailling pins, with the centerlines of pins and corresponding holes in the brailling beam remaining parallel. The direction of this off-set was chosen in three different ways (see Fig. 28) to subject the brailling pin bearing leafsprings to different loads: Direction A produces an extra compression in the top-leafsprings, direction B has a twisting effect and direction C produces extra tensile stresses in the top springs.

The tests showed that when the value of the mis-alignment did not exceed 0.25 mm, no influence could be determined on the shape of the produced braille dots. When the mis-alignment is larger than 0.25 mm, the side where the clearance between pin and hole is at its smallest value starts cutting the paper, producing a braille dot which is partly punched out of the paper. Increasing the mis-alignment up to 0.5 mm increased this punching effect

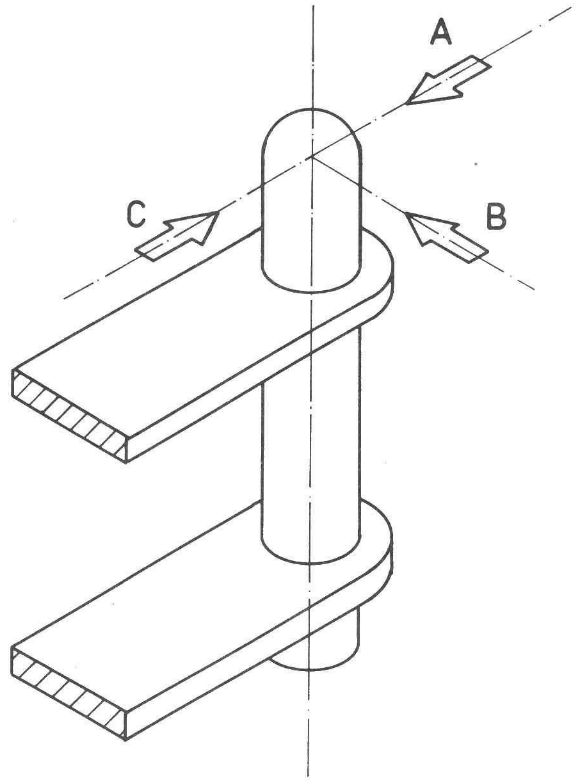


FIGURE 28

Mis-alignment directions with respect to the brailling pin bearing springs.

further, but did not damage the leafspring bearings of the pins. Restoring the original position (zero mis-alignment) produced a braille dot of the right shape again. The direction of the mis-alignment had no effect on the above mentioned phenomena.

7.4.2 Joints between brailling pins and leafsprings.

This test was set up to determine whether a "snap-action" joint was feasible between brailling pins and their bearing springs.
The idea was to produce brailling pins with two grooves with widths slightly larger than the thickness of the spring materials. With the ends of each spring shaped like in Fig. 29; it should be possible to push the pin between the two bendable parts and "snap" them in.
After some research in order to find the best form of the spring end to let pass the pin without plastic deformation and yet give maximum "grip", a test was set up to determine the reliability of this connection. For

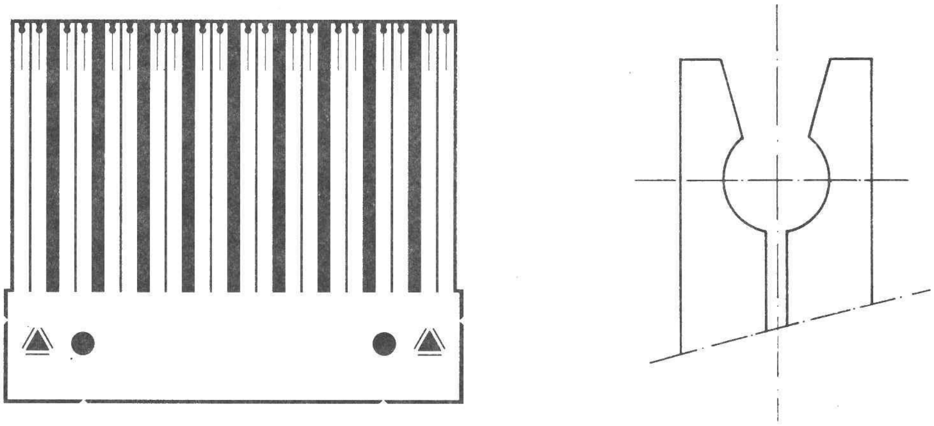


FIGURE 29

Shape of the spring ends for a "snap" joint.

this purpose a set of forty pins was tested by moving them repeatedly over a stroke of 1.5 mm in the direction of their centerline. This was done by clamping the leafsprings and pushing the brailling pins away from their nominal position by an oscillating beam with forty pins mounted in it. The end surfaces of these pins (each working together with one brailling pin during this test) had different angles to the centerline of the pins and different orientations with respect to the length axis of the leafsprings. This was done to introduce loads in all three directions of Fig. 28.
The test indicated that this method of connecting leafspring and brailling pin was not reliable, because some pins worked loose of their respective springs after approximately one million cycles. The connection was then made by just etching a round hole from the spring ends and then glueing.

7.4.3 Connection between selectionblocks and wire springs.

A connection that gave some trouble in the prototype phase was the one between the selectionblocks and the wire springs that cause their movement (partnrs 31 and 74).
Originally this joint was made by glueing these parts together, using Araldite, after a hole had been drilled in the selectionblock with a diameter 0.1 mm larger than the wire spring diameter. This procedure proved to be unsufficient however: Some blocks were found beneath their original position, after a few hours printing with the prototype. Analysis revealed that always the connection between glue and wire spring had failed, never

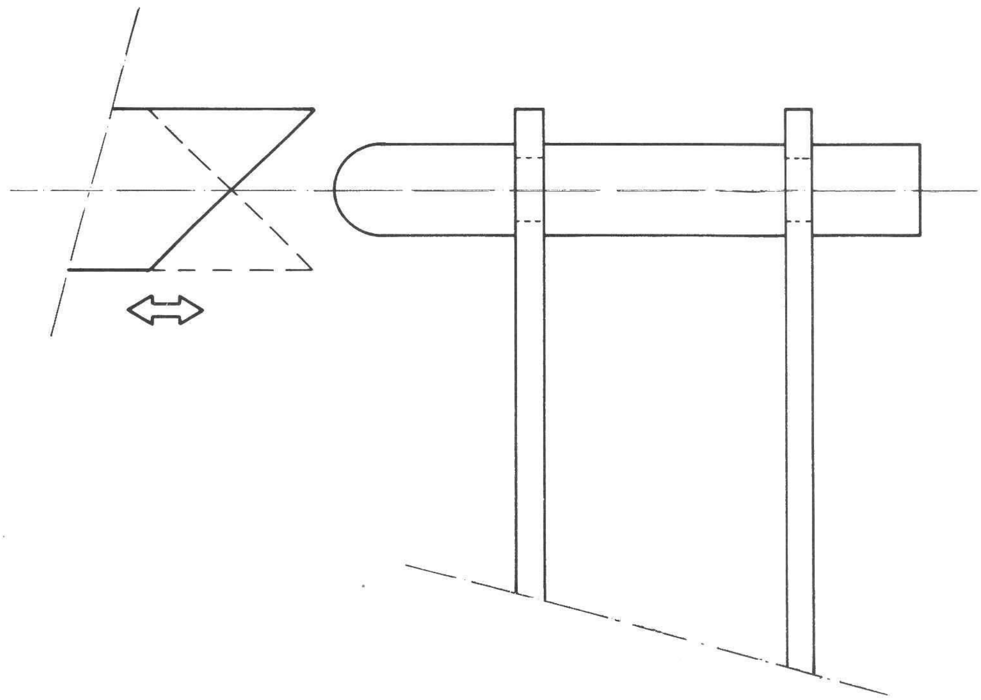


FIGURE 30

Test set-up for pin-spring connections.

the one between glue and selectionblock. The cause for this failure was probably the very smooth surface of the (drawn) wire spring. The problem was solved by a slight etching of that part. This extra treatment solved this problem; during all later tests all selectionblocks remained in position.

7.4.4 The papertransport system.

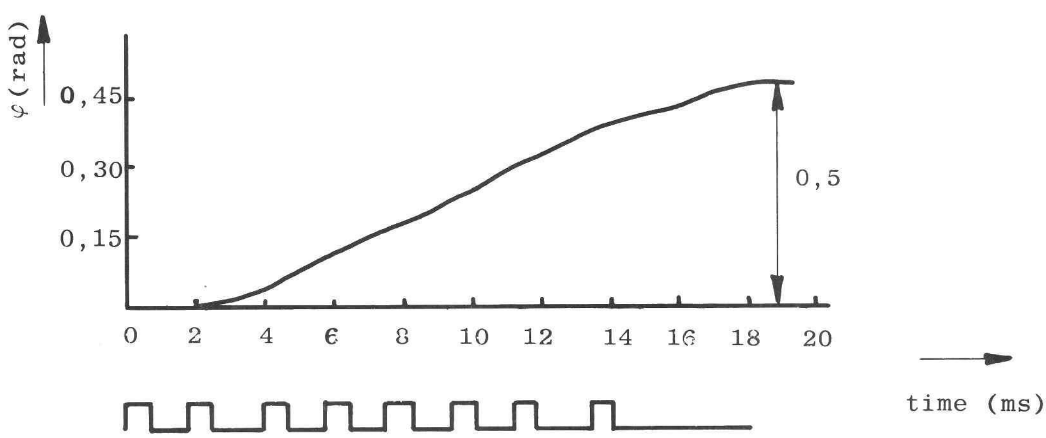


FIGURE 31

Position of papertransport shaft vs.time during 5 mm step.

(Optimized pulse sequence.)

This section shows the influence of the pulse frequency to the papertransport steppermotor on the actual paper movement. Fig. 31 shows the position of the papertransport tractor shaft (pos.nr 36) as function of time, when the steppermotor is fed with the pulse sequence that is indicated in the same figure. This is the shaft movement that results after optimizing the pulse sequence for the 5 mm papertransport step. Fig. 32 shows the shaft movement as function of time when the interval times 4, 5 and 6 are too short: The motor starts loosing steps and the accompanying paper advance is smaller than 5 mm.

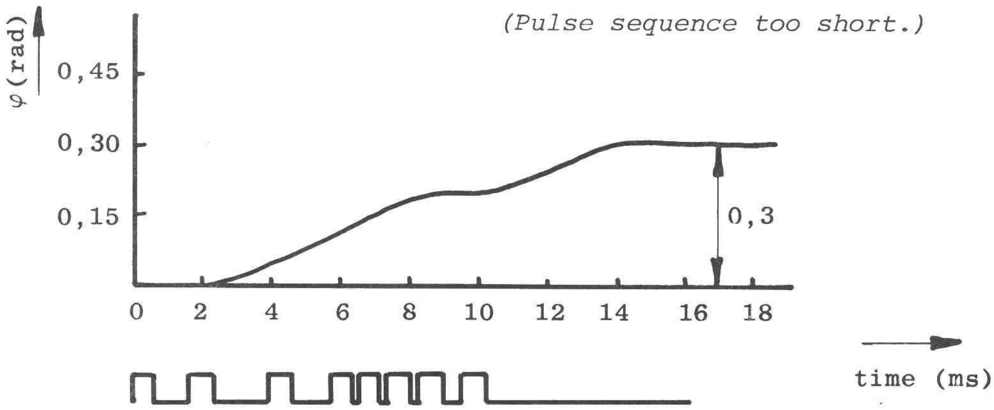


FIGURE 32

Papertransport shaft position vs. time during 5 mm step.

The next two figures show the 2.5 mm paper transport movement: Fig. 33 shows the movement with the optimized pulse sequence and Fig. 34 shows what happens if the pulses are spread over the available time span for this movement (15 ms). The motor stops shortly after each pulse and this produces extra noise and presumably extra wear. From these figures it can be concluded that the steppermotor starts moving 2 ms after the first steppulse, so it needs a fixed "synchronization advance" of 2 ms. The optimum pulse sequences were derived by individually changing each interval time, starting with the first, in order to exploit the maximum steppermotor torque at all motorspeeds, resulting in a clean rotormovement without losing steps and without overshoot.

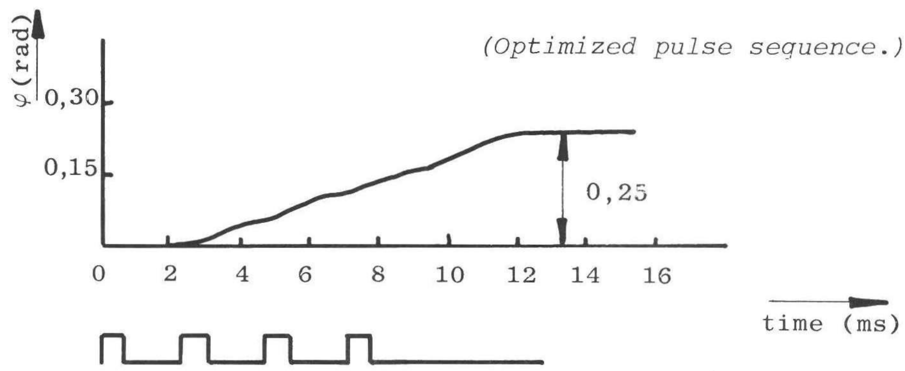


FIGURE 33

Papertransport shaft position vs. time during 2.5 mm step.

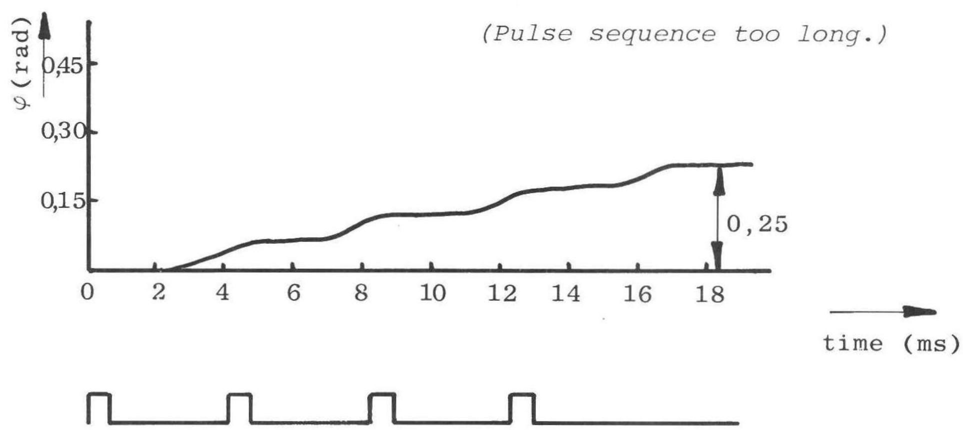


FIGURE 34

Papertransport shaft position vs. time during 2.5 mm step.

7.4.5 <u>The selection system</u>.

To get an impression about the actual movement of the selectionblocks, their movement was recorded by means of a high-speed camera. The analysis of this film revealed that the movement of the selectionblocks was exactly according to the curves of both cams on the camshaft. A difference could occur for instance in the duplex-movement direction, because every extra bending of the wiresprings caused by mass forces could create extra resonances. However the thickness of the wire springs proved to be sufficient to prevent this.

7.4.6 The duplex system.

Figure 35 shows the system employing two solenoids that was tested for the duplex movement. The two solenoids are at the bottom of the picture and fixed to the (black) fixed beam that runs from left to right in the middle of the picture. On top of this fixed beam the (aluminium coloured) duplex-beam and the two leafsprings that form its bearing system can be seen. The leafspring clampings are also connected to the fixed beam. The two plungers of the solenoids are connected to each other by means of a very thin rod (1 mm diameter steel wire). This is done to get a connection that is stiff in only one direction to avoid alignment problems between the directions of the plunger movement and the duplex-beam movement. A slight mis-alignment is taken up by bending of this (spring steel) wire. Clamped to the middle of this wire is the connection rod to the duplex-beam. This enables an easy adjustment of the symmetry of this drive system.

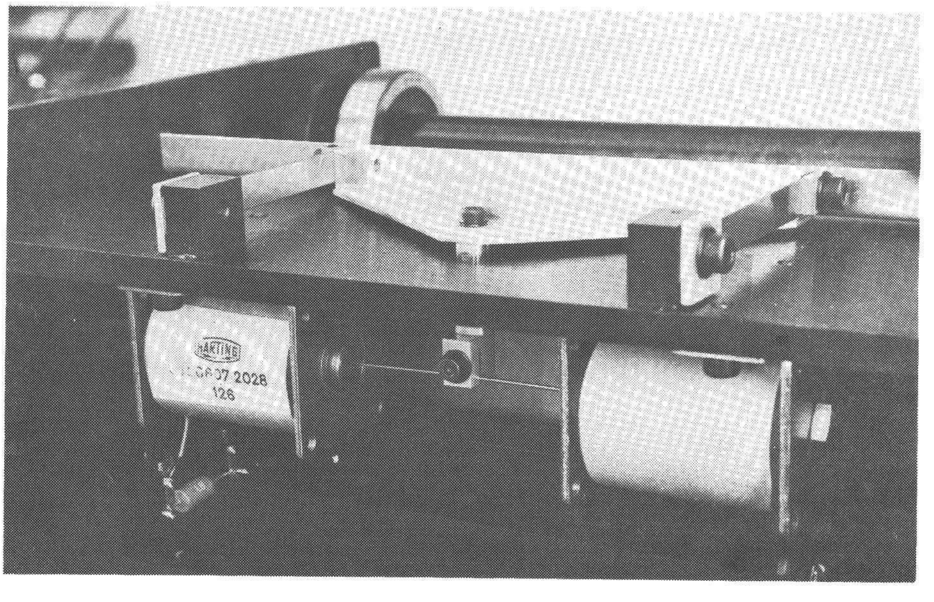


FIGURE 35

Solenoid driven duplex system in the laboratory prototype.

Fig. 36 shows the displacement of this system as a function of time. This recording was made using a camera that "looks at" a black-white transition on the moving object and gives an electrical output voltage that is proportional to the position of the black-white transition.

By changing the spring rate of the leafspring bearing of the duplex-beam it was tried to achieve a smooth fast movement, but as stated earlier, this was not succesfull.

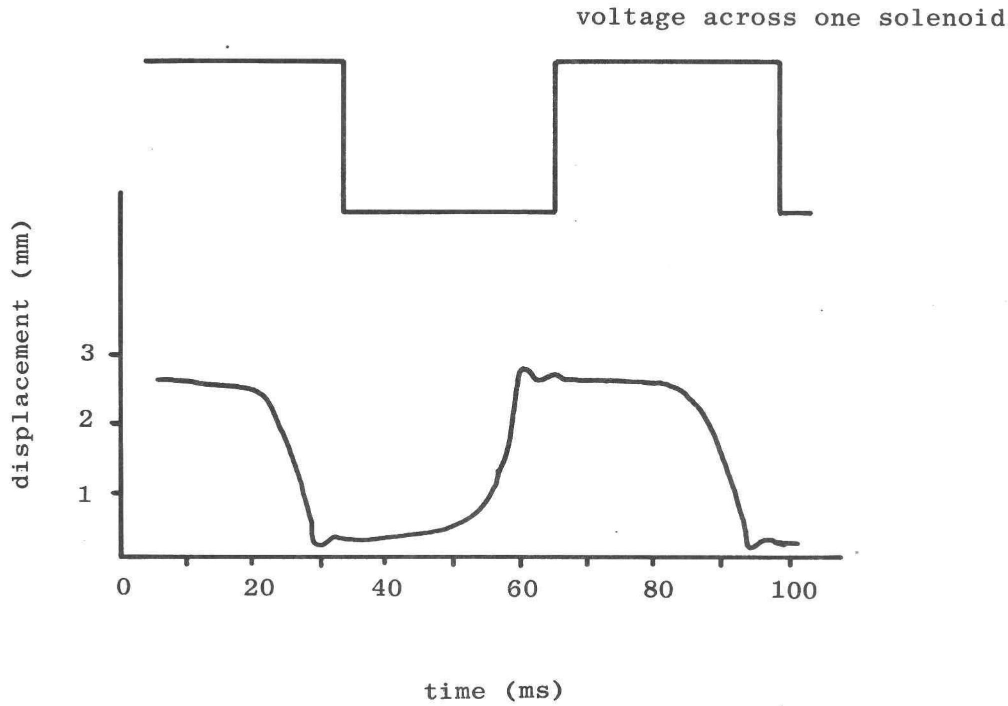


FIGURE 36

Displacement of the solenoid driven duplex system vs. time.

7.4.7 Noise production.

The elements in the braille lineprinter that appeared to be the noisiest during the first runs with the printer, were the cam-follower combinations for selection movement and duplex movement. This was caused by the remaining grooves of the manufacturing process (milling) on the cams. With the high speed of these cams this produced a clearly audible noise. This noise was greatly reduced by polishing the cams and the application of grease on the contacting surfaces. A further reduction of the produced noise was achieved by covering the inside of the lineprinter cover plates with a 3 mm thick foam layer. Another noise source is the paper that is hit during each cycle of the lineprinter by the oscillating brailling-beam. No measures were taken to cope with this noise. Even in the uncovered prototype version the noise seemed tolerable for a piece of office equipment.

7.4.8 Wear at contact surfaces.

After printing about 12000 lines the lineprinter was partly disassembled to look at those places where wear could be expected.
The surfaces of the cams were "run in" but showed no wear. So was the brailling-beam at the places where the rollers (partnr 4) had been in contact with it: Locally the manufacturing grooves were "rolled out" yielding a flat shiny surface, but no wear could be detected. The same can be said of the working surfaces of selectionblocks and fixed beam (partnr 47). (The selectionblocks were hardened till HRC 58, while the surface of the fixed beam was not treated.) Between the sliding surfaces some MoS_2-powder ("Molykote") had been applied as a lubricant.
Further testing with the brailling pins and the brailling-beam was continued till the equivalent of 300.000 lines was printed. Then the form of the tops of the brailling pins was compared with their original form with the aid of a profile projector. No difference with the original could be spotted. The same holds for the edges of the holes that work together with the brailling pins to form the braille dots (partnr 21): the edges were still sharp.
Fig. 37 shows a set of brailling pins that was used in this test.

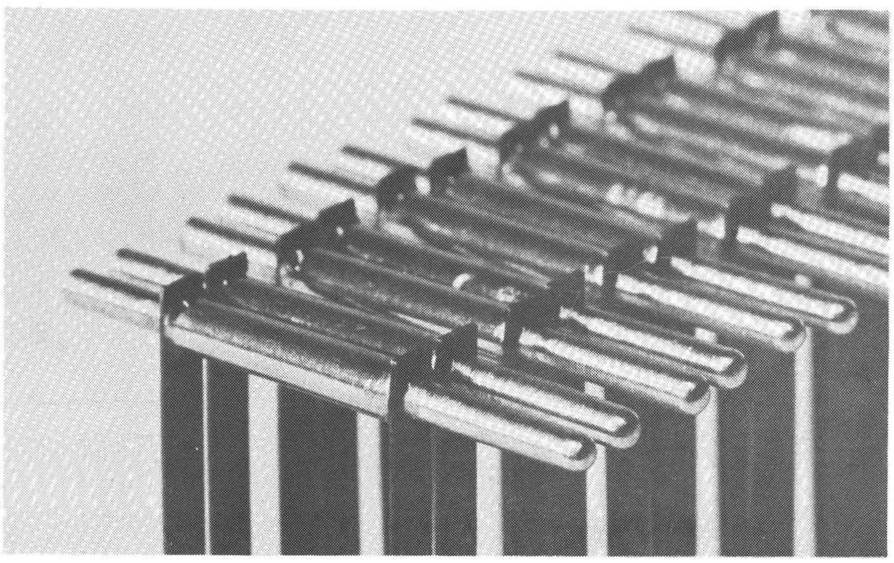


FIGURE 37

A set of brailling pins used in the tests.

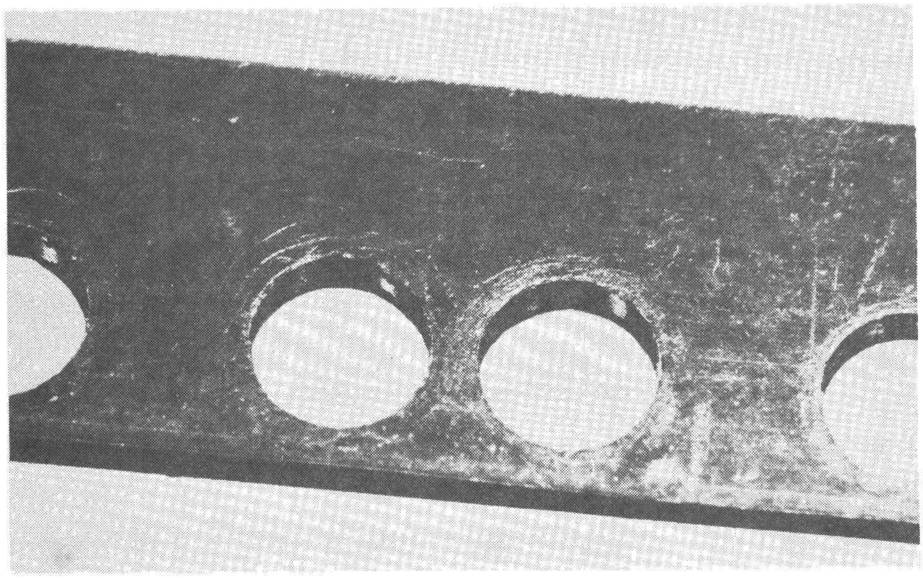


FIGURE 38

Typical holes from brailling die (partnr 21) before use.

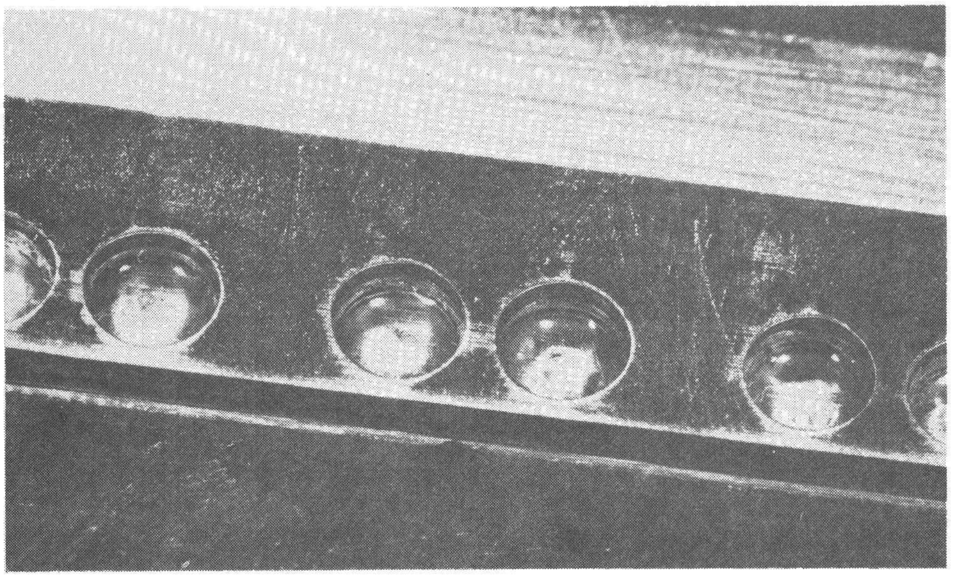
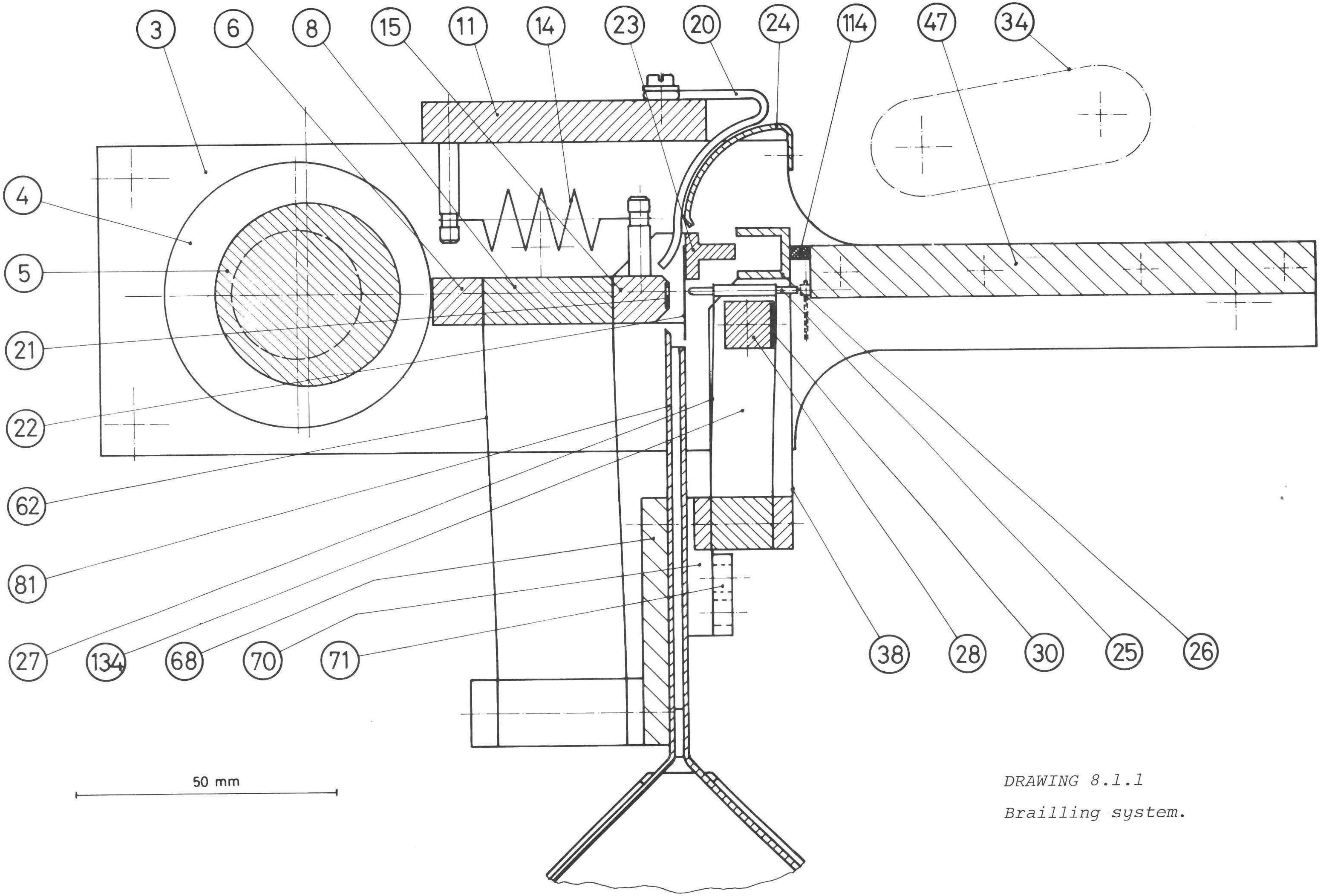


FIGURE 39

Typical holes from the brailling die (partnr 21) after brailling 300,000 lines.

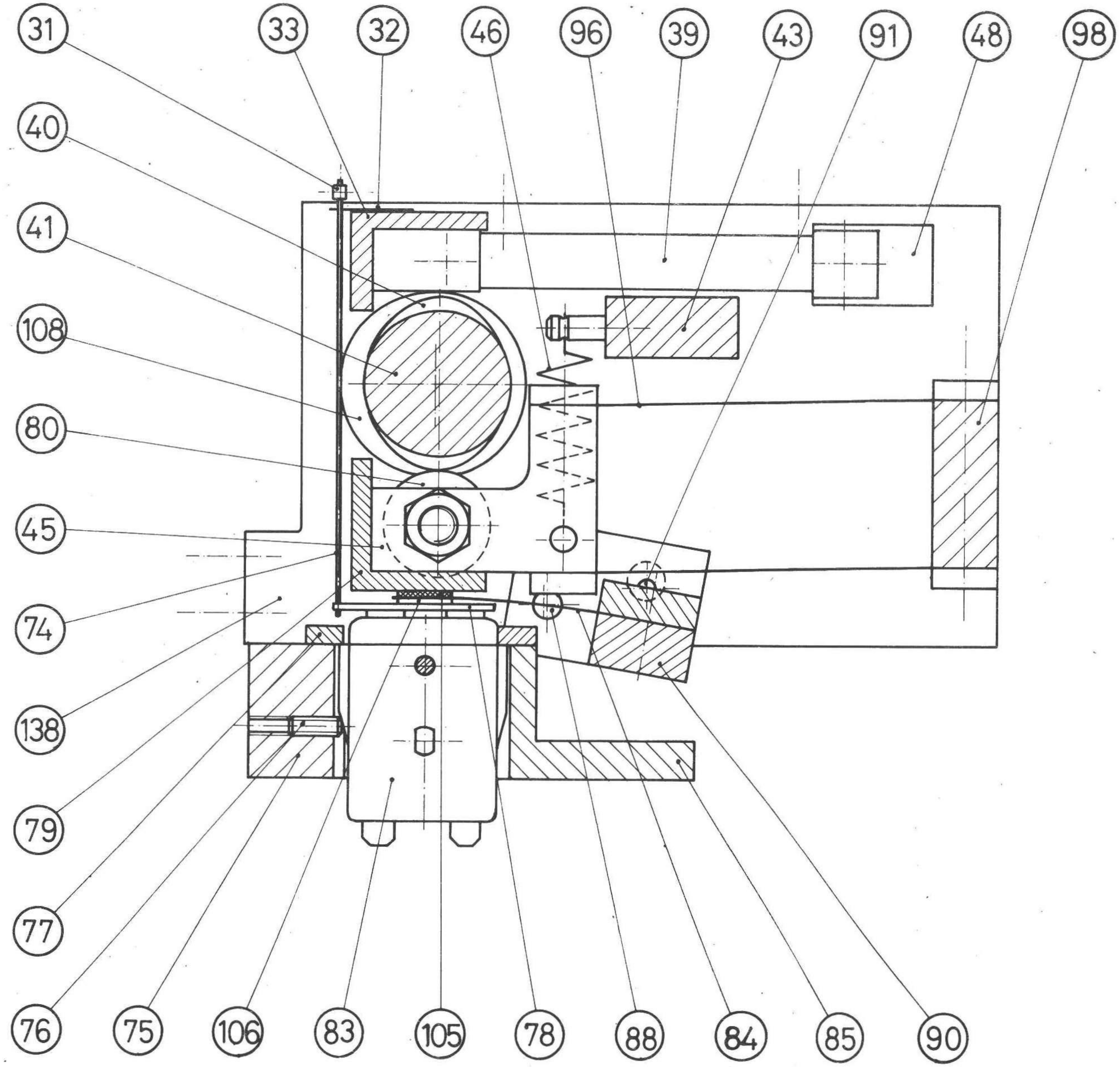
8. APPENDIX.

8.1. Mechanical engineering drawings.



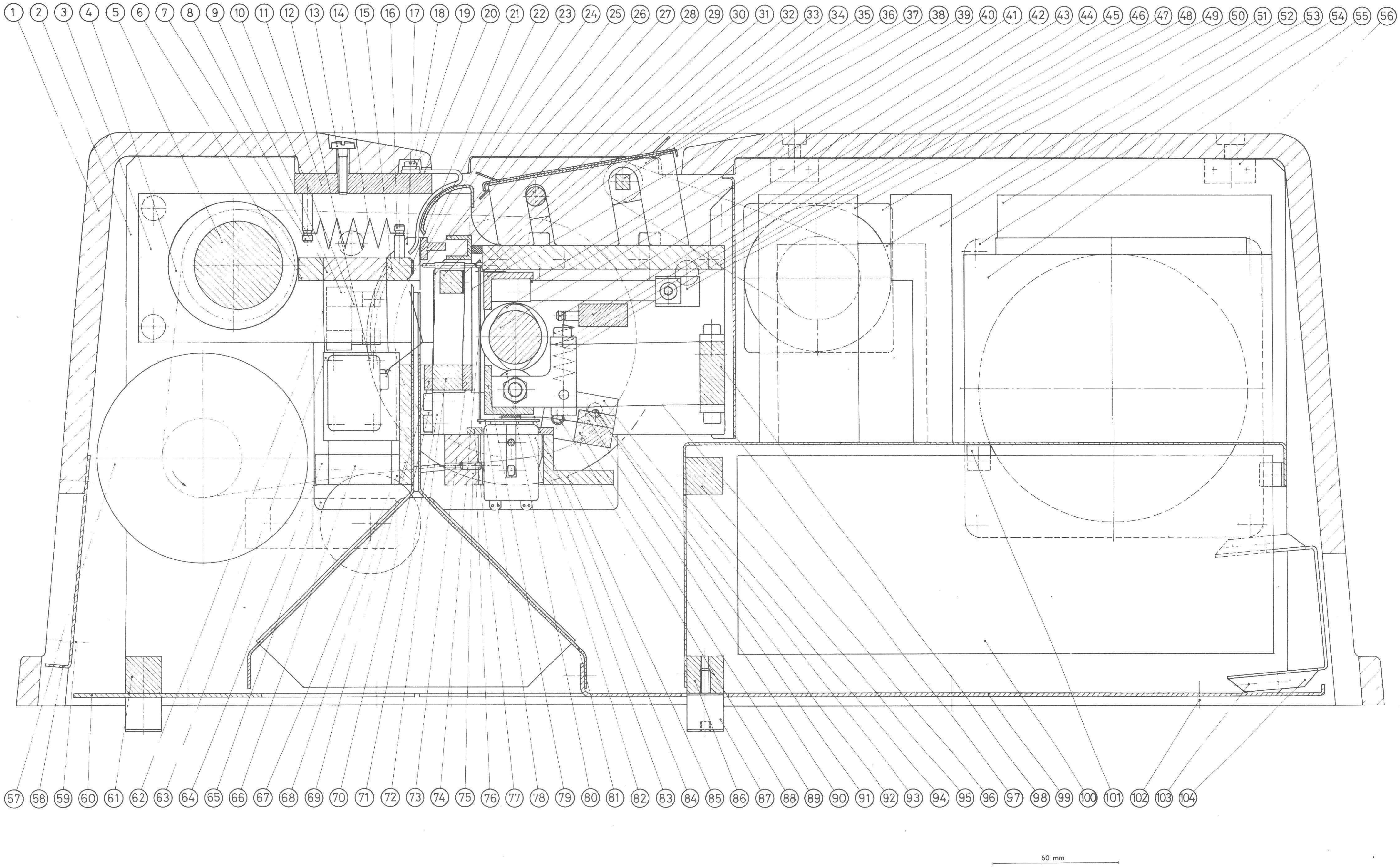
DRAWING 8.1.1

Brailling system.



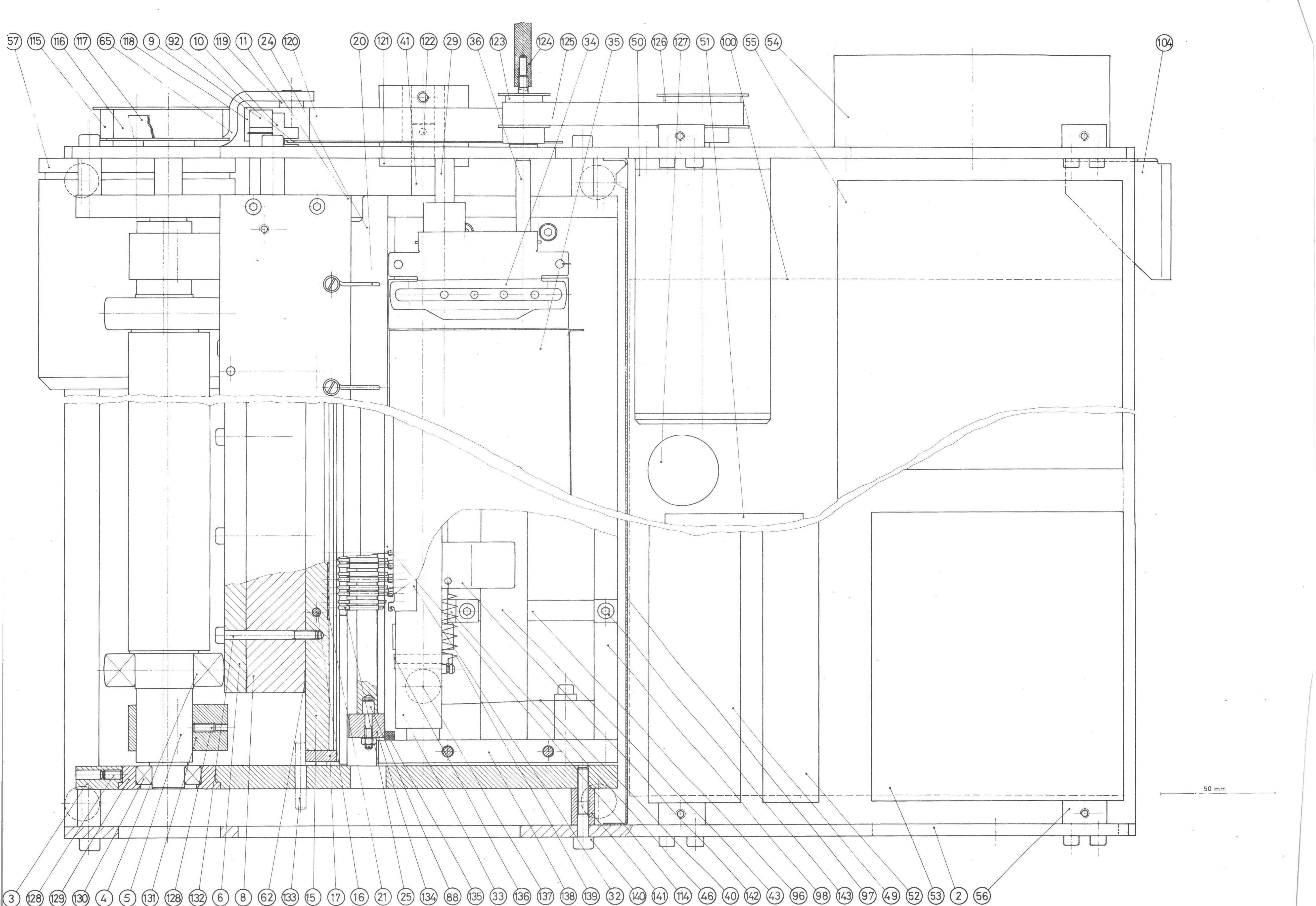
DRAWING 8.1.2

Selection system.



DRAWING 8.1.3

Braille lineprinter assembly.



DRAWING 8.1.4

Braille lineprinter assembly.

STUK Nr.	AANTAL	OMSCHRIJVING	AFMETINGEN	MATERIAAL	OPMERKING
143	10	CYLINDER HEAD SCREW M4x15 NEN 1241			
142	1	SPRING FASTENING PLATE THICKNESS 1 AL			
141	8	DISTANCE TUBE		AL	
140	8	CYLINDER HEAD SCREW M5x30_NEN 1241.			
139	1	HELICAL SPRING	ø 1,4 LENGTH 37 14 TURNS ø8 SPRING STEEL		
138	2	SIDEPLATE SUBFRAME		AL	
137	1	FOLLOWER		INA KR 16 PP	
136	1	AXIAL CAM		ST	
135	2	DUST SEAL	ø5	SPONGE RUBBER	
134	2	ROD		AL	
133	2	PIN AS MOUNTING AID ø5x30		ST 50	
132	7	CYLINDER HEAD SCREW M4x20 NEN 1241			
131	2	BALANCING MASS		ST 50	
130	2	BALL BEARING			SKF 6001-2RS
129	2	ADJUSTING RING		ST 50	
128	4	SET SCREW A-M4x10-NEN 2343			
127	1	MAIN MOTOR CONDENSER			8µF - 400V
126	1	PULLEY		VAN GELDER 21 XL 037 6F	
125	1	TIMING BELT		VAN GELDER 50 XL	
124	1	PAPER ADJUSTING KNOB		NYLON	
123	1	PULLEY		VAN GELDER 10 XL 037 6F	
122	1	LOCKING PIN		ST 50	
121	1	CONNECTING BUSH		AL	
120	1	PULLEY		VAN GELDER 60 XL 037 6A	
119	1	TENSION PULLEY SPINDLE		AL	
118	1	TENSION PULLEY		AL	
117	1	TIMING BELT		VAN GELDER 107 XL	
116	1	PULLEY		VAN GELDER 30 XL 037 6F	
115	1	PULLEY		VAN GELDER 20 XL 037 6F	
114	1	DUST SEALING STRIP ø5		SPONGE RUBBER	
108	2	ECCENTRIC BUSHING		AL	
107	1	PIN	ø3x250	ST	
106	40	BLOCK	THICKNESS 1	SPONGE RUBBER	
105	1	STRIP	THICKNESS 1	SPONGE RUBBER	
104	1	PLATE	THICKNESS 1	STAINLESS STEEL	
103	4	CYLINDER HEAD SCREW M4x5-NEN 1241			
102	12	CYLINDER HEAD SCREW M3x8-NEN 1241			
101	4	CONNECTING PLATE	THICKNESS 0,5	ST	
100	1	MICROPROCESSOR CARDCAGE			INTEL SBC 604
99	1	REAR BOTTOMPLATE THICKNESS 1,5 AL			
98	1	CONNECTING BEAM		AL	
97	1	PARTITION PLATE	THICKNESS 0.5	SPRING STEEL	
96	1	LEAF SPRING	THICKNESS 0,5 SPRING STEEL		
95	1	CONNECTING BEAM ø15x430		AL	
94	1	SUPPORT PLATE ELECTRONICS THICKNESS 0,5 ST			
93	1	MOUNTING PLATE		AL	
92	1	TIMING DISK		AL	
91	2	CYLINDER HEAD SCREW M4x18-NEN 1241			
90	1	CLAMPING BLOCK		ST 50	
89	1	CLAMPING BEAM		ST 50	
88	4	ADJUSTING ECCENTRIC		AL	
87	4	SUPPORT RUBBER		ERIKS VIBROSTOP 2062 UITV. B	
86	1	CONNECTING BEAM	ø15x430	AL	
85	1	MOUNTINGBEAM SELECTIONMAGNETS L 30x20x6x370 AL			
84	4	LEAFSPRINGCOMB		SPRINGSTEEL	
83	40	SELECTION MAGNET		HARTING 08 01501 0107	
82	4	STIFFENING PLATE	THICKNESS 0.2 SPRING STEEL		
81	1	PAPERFEED GUIDING		AL _ INSIDE TEFLON COATED	
80	2	FOLLOWER			INA KR 16 PP
79	1	PRESSING BEAM	L 20x20x3x250 AL		
78	40	ARMATURE		SOFT IRON	
77	2	CLAMPING BLOCK		ST 50	
76	40	SET SCREW A-M3x8-NEN 2343			
75	1	MOUNTINGBEAM SELECTIONMAGNETS AL			
74	40	WIRESPRING	ø0,4	SPRING STEEL	
73	1	CLAMPING STRIP		AL	
72	1	CLAMPING BEAM BRAILLING PINS		AL	
71	2	CONNECTING PLATE		ST 50	
70	2	CONNECTING BLOCK		AL	
69	1	CLAMPING STRIP		ST 50	
68	1	MOUNTING PLATE		AL	
67	2	DISTANCE BLOCK		AL	
66	2	DISTANCE BLOCK		AL	
65	1	TENSION PULLEY BRACKET		AL	
64	2	CLAMPING BLOCK		ST 50	
63	1	SWITCH SUPPORT	THICKNESS 1	AL	
62	4	GUIDING LEAFSPRING BRAILLINGBEAM THICKNESS 0,6 SPRING STEEL			
61	1	CONNECTING ROD	ø15x430	AL	
60	1	BOTTOMPLATE	THICKNESS 1,5	AL	
59	4	SELF-TAPPING SCREW ø3x12			
58	1	SWITCH BOARD	THICKNESS 1	AL	
57	1	MAIN MOTOR		PAPST KLZ 42.60-2B 204	
56	4	FASTENING BLOCK FOR CASE		AL	
55	1	POWER SUPPLY MICROPROCESSOR			INTEL SBC-630
54	1	BLOWER			
53	1	POWER SUPPLY CARD STEPPERMOTOR			
52	1	CONTROL PCB STEPPERMOTOR			
51	1	SUPPLY TRANSFORMER SELECTIONMAGNETS			
50	1	STEPPERMOTOR		BERGER RDM 569/50	
49	1	POWERSUPPLY PCB SELECTIONMAGNETS			
48	2	MOUNTING BLOCK		AL	
47	1	FIXED BEAM		ST 50	
46	2	CONNECTING BLOCK		AL	
45	2	HELICAL SPRING	ø1,6 LENGTH 29 13 TURNS ø8 SPRING STEEL		
44	12	CLAMPING BLOCK		ST 50	
43	1	CONNECTION ROD		AL	
42	4	SPRING FASTENING PIN ø4x15		ST 50	
41	1	CAMSHAFT		ST 50	
40	2	RADIAL CAM		ST	
39	2	GUIDING SPRING DUPLEXBEAM THICKNESS 0,4 SPRING STEEL			
38	1	DUSTCOVER	THICKNESS 0,1	SILICONE RUBBER	
37	1	PAPERSUPPORT PLATE, RIGHT THICKNESS 1 AL _ TEFLON COATED			
36	1	MAINSHAFT PAPERTRACTION			DEC 74-11075-00
35	1	PAPERSUPPORT PLATE, LEFT THICKNESS 1 AL _ TEFLON COATED			
34	2	PAPERTRACTOR			DEC 12-11662-04/05
33	1	DUPLEXBEAM	L-20x15x3x320 AL		
32	4	GUIDING PLATE	THICKNESS 0,3	SPRING STEEL	
31	40	SELECTIONBLOCK		ST	HRC: 58
30	1	DAMPING RUBBER	THICKNESS 0,5		
29	1	SUPPORT ROD FOR PAPERTRACTORS			DEC 74-11076-00
28	1	STOPBEAM		ST 50	
27	4	COMB OF LEAFSPRINGS THICKNESS 0,2 SPRING STEEL			
26	1	U-PROFILE	10x10x1,5x370	AL	
25	80	BRAILLING PIN		STAINLESS STEEL	
24	1	PAPER GUIDING PLATE THICKNESS 1		AL	TEFLON COATED
23	1	T-PROFILE	10x9x3x370	AL	
22	4	PAPERLIFTING PLATE THICKNESS 0,2		SPRING STEEL	
21	4	BRAILLING DIE	THICKNESS 0,7	SPRING STEEL	
20	7	PAPERGUIDING	ø1,5	STAINLESS STEEL	
19	7	WASHER A-3,2-NEN 2269-ST			
18	7	CYLINDER HEAD SCREW M3x10		ST	
17	2	CONNECTING BLOCK		AL	
16	2	SPRING FASTENING PIN ø4x20		ST 50	
15	1	BRAILLING BEAM, FRONT PART		ST 50	
14	2	HELICAL SPRING	ø1,8 LENGTH 35 10 TURNS ø12 SPRING STEEL		
13	6	CONVEX HEAD SCREW	M4x15	STAINLESS STEEL	
12	1	MICROSWITCH		ROBERTSHAW 1CMD1-18AXX-A22-45	
11	1	TOPBEAM BRAILLINGFRAME		AL	
10	2	OPTICAL SWITCH			MONSANTO MCA 81
9	1	SUPPORT FOR OPTICAL SWITCHES		AL	
8	1	BRAILLING BEAM, CENTRE PART		AL	
7	2	SPRING FASTENING PIN ø4x25		ST 50	
6	1	BRAILLING BEAM, REAR PART		ST 50	
5	1	MAIN SHAFT		ST 50	
4	2	ROLLER			SKF 361204
3	2	BRAILLINGFRAME SIDEPLATE		AL	
2	2	MAINFRAME PLATE		AL	
1	1	CASE		P.U.R.-FOAM	

SCHAAL:		DATUM
GET.:	N.R.KEMPER	1978-12
GEC.:	WESTLAND	
GEZ.:		

BEWERKINGSTEKENS VOLGENS NEN 3637

WIJZ.	OMSCHRIJVING	DATUM	PARAAF

BENAMING:

Braille lineprinter 3

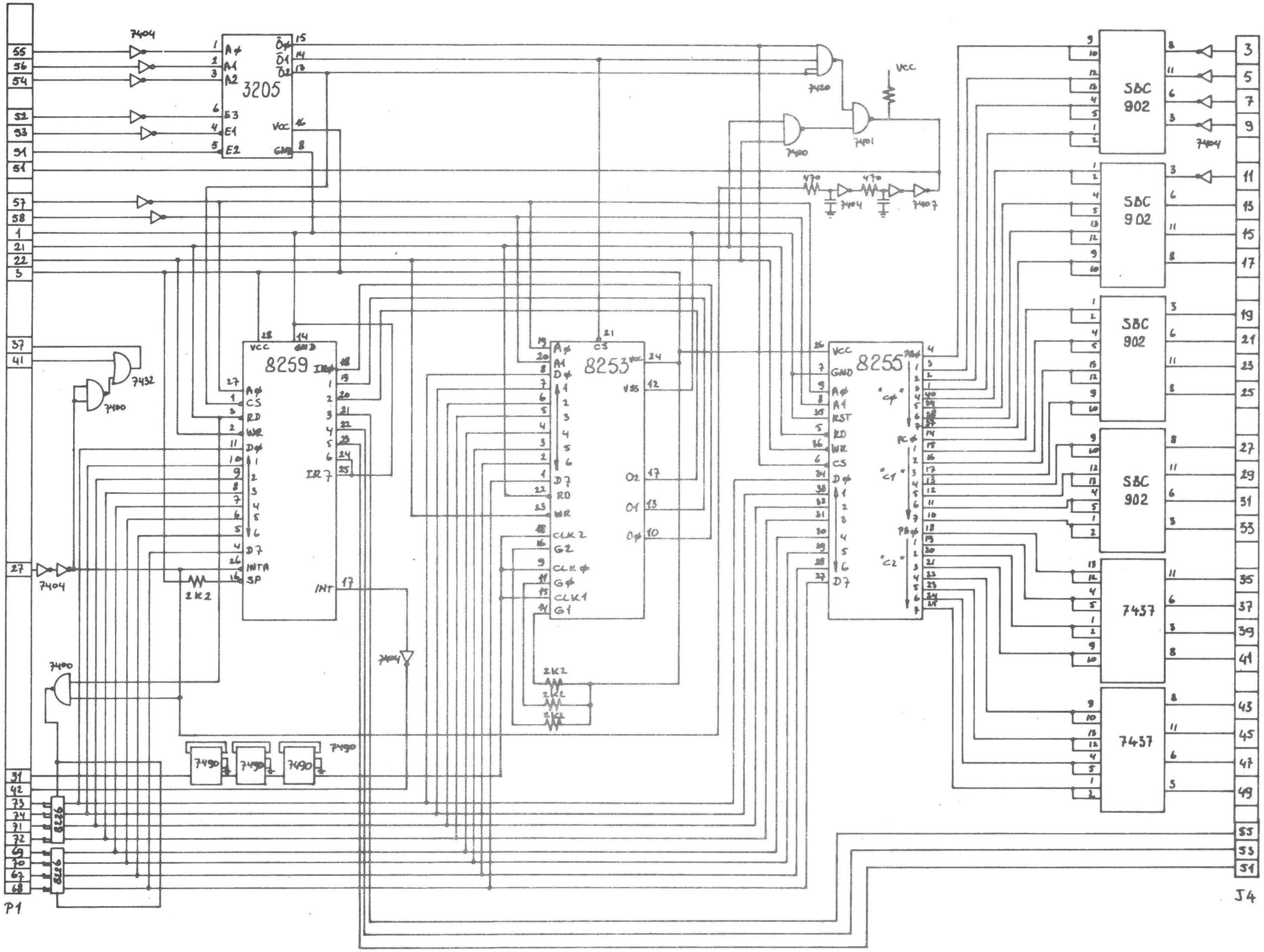
VAKGROEP
WERKTUIGBOUWKUNDIGE
PRODUKTIETECHNIEKEN.
SEKTIE: FMT

FORMAAT | TEK.Nr.

AANT. BLADEN: | BLAD Nr.

Braille lineprinter parts list.

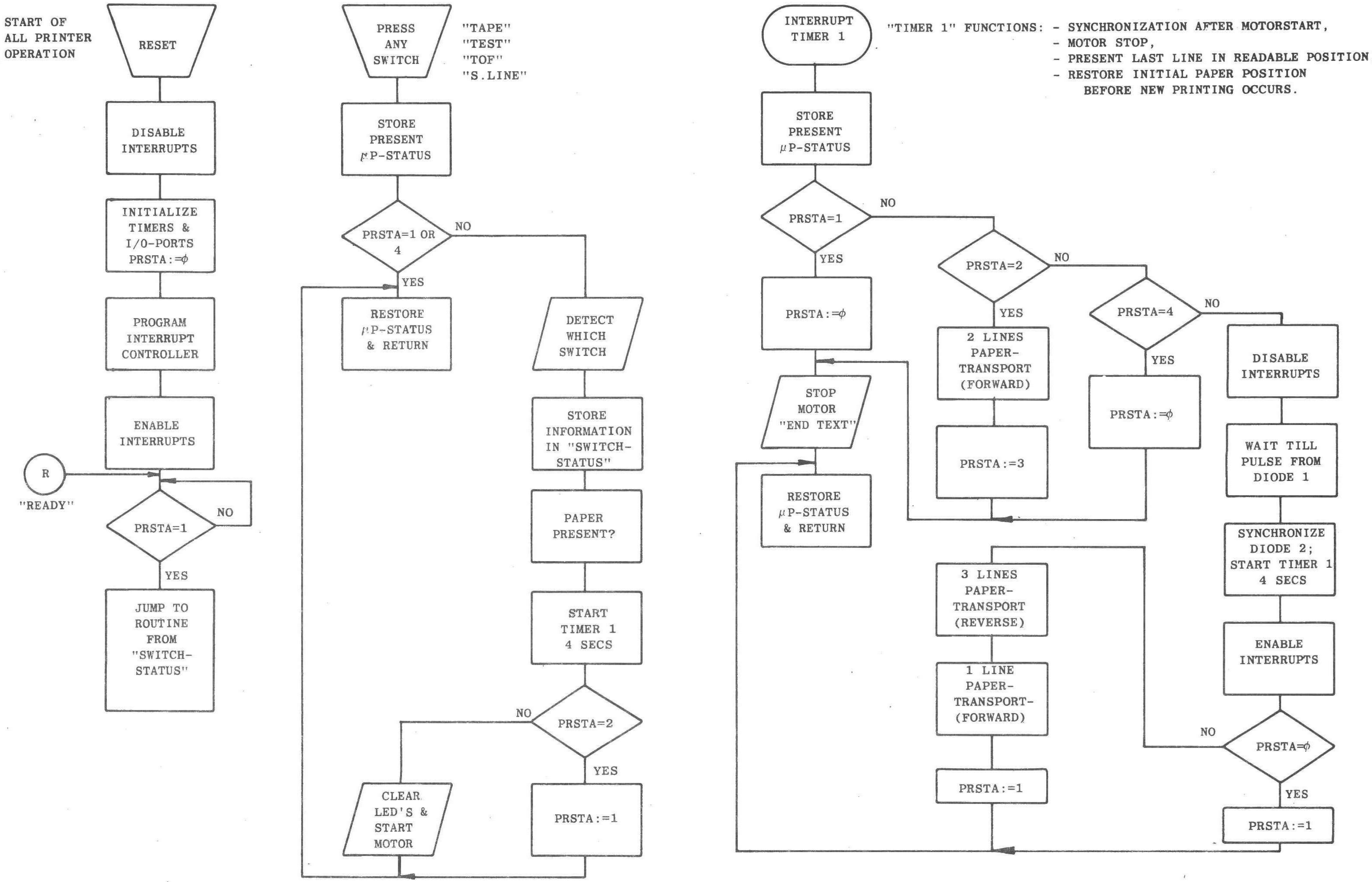
8.2. Schematics of the electronic hardware.



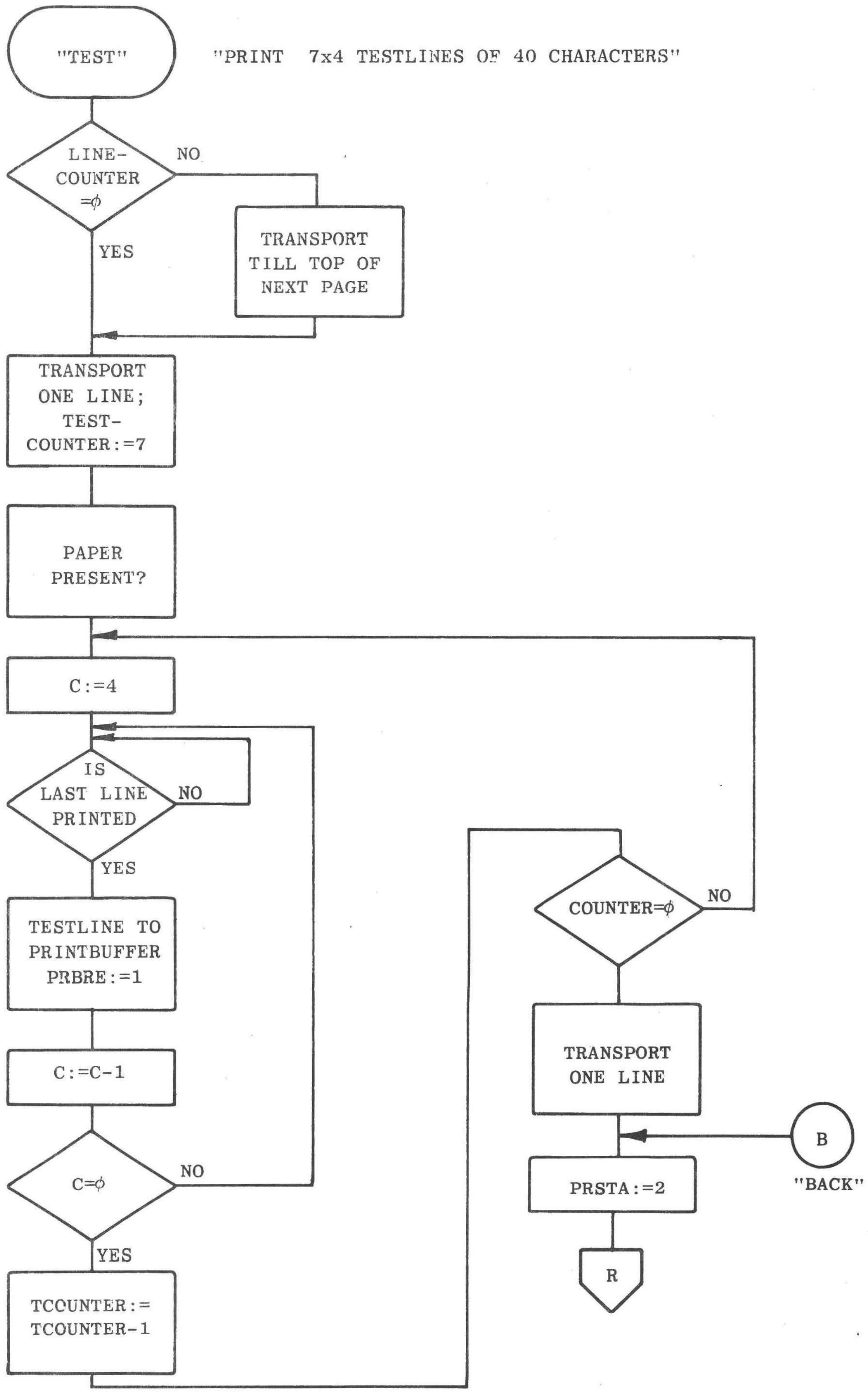
DRAWING 8.2.1

Components on expansion board.

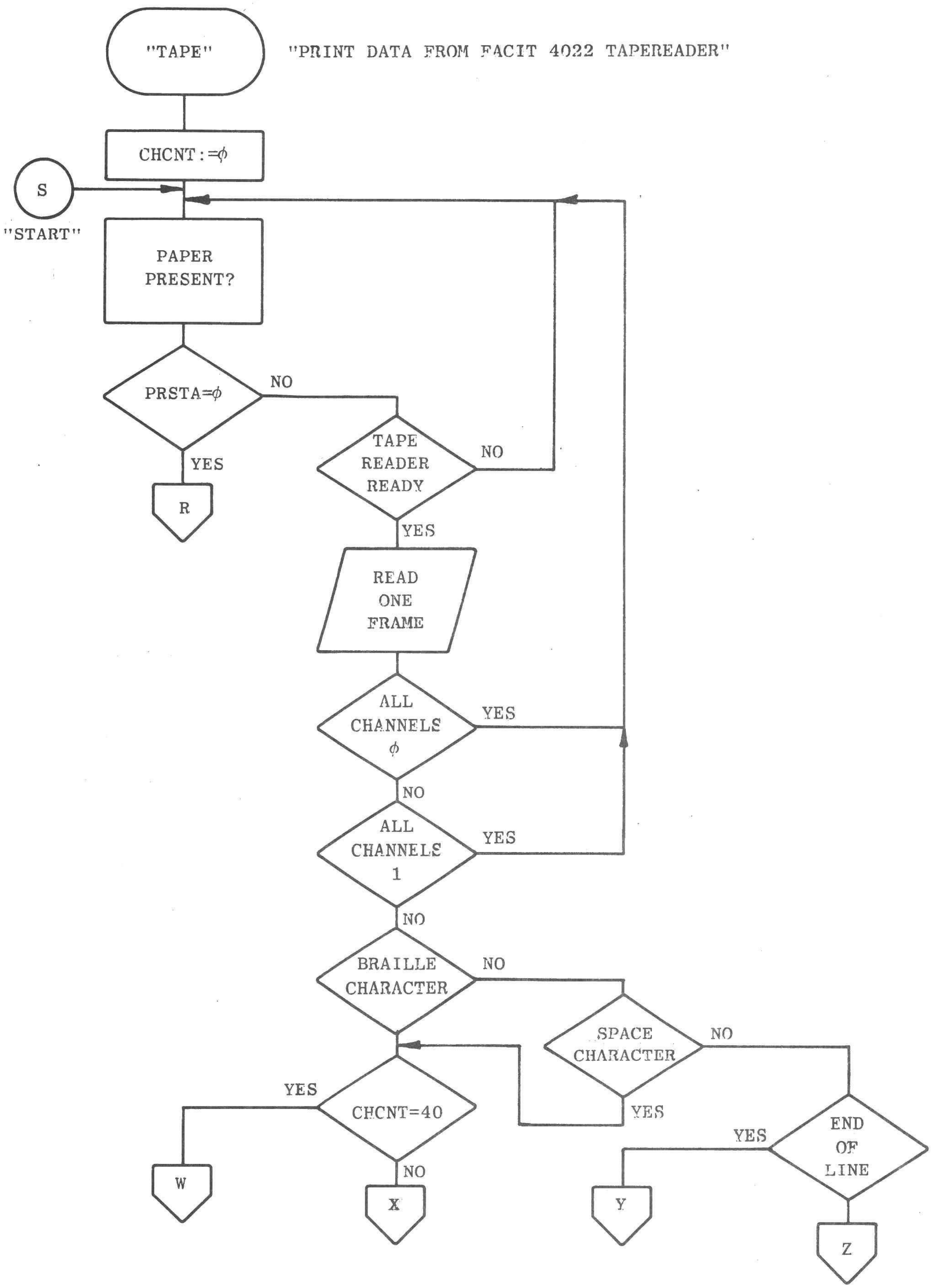
8.3. Control software flowcharts.



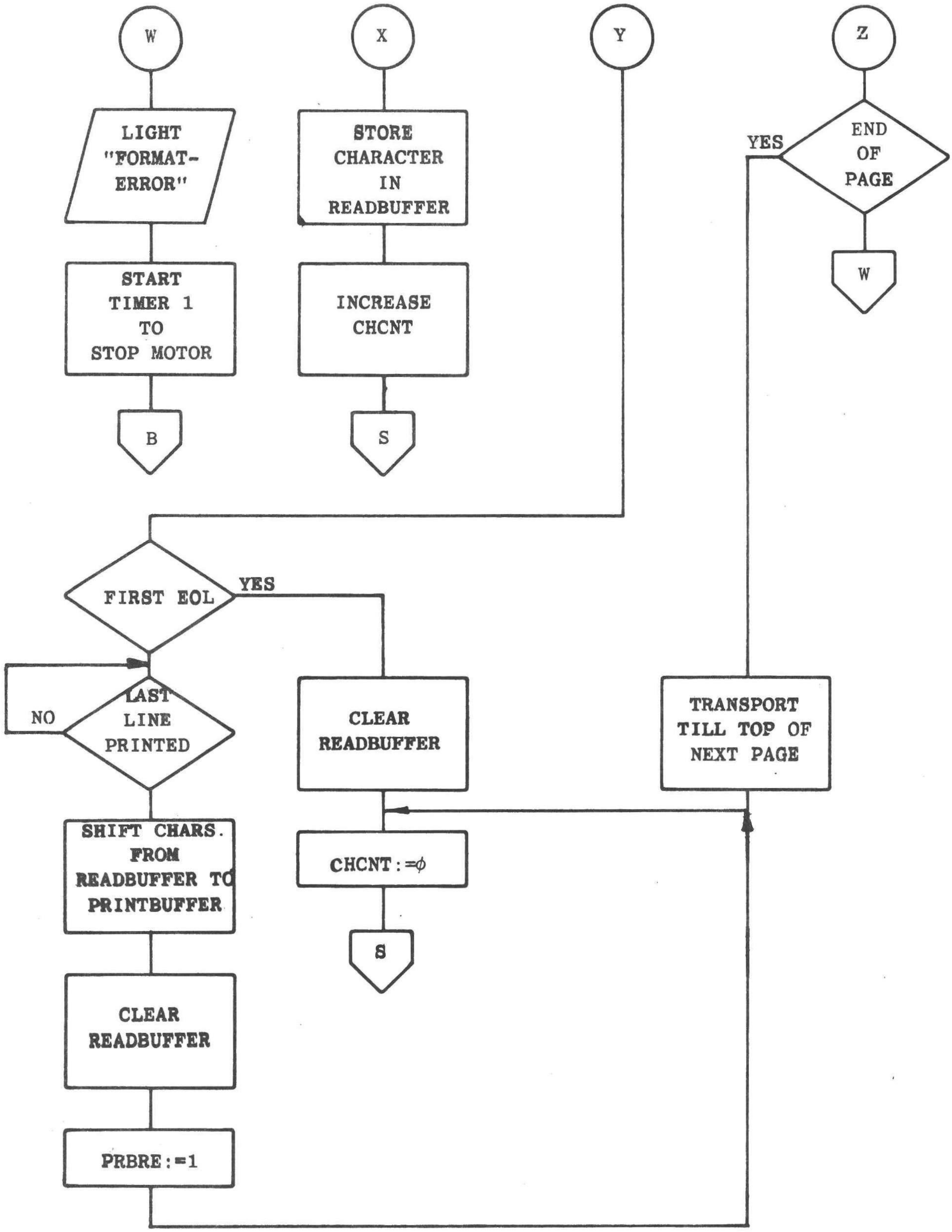
Braille lineprinter driver - Flowchart 1.



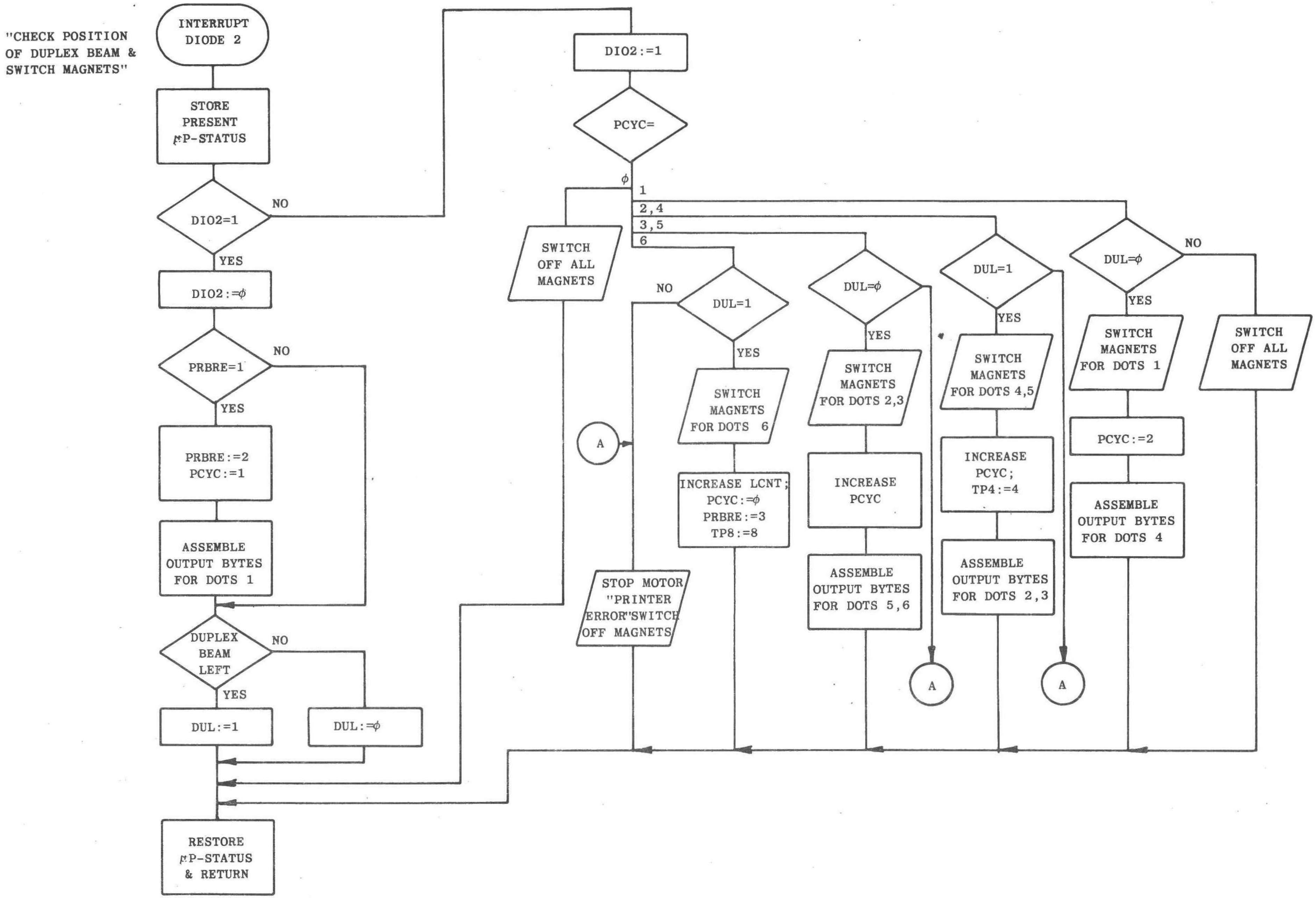
Braille lineprinter driver - Flowchart 2.



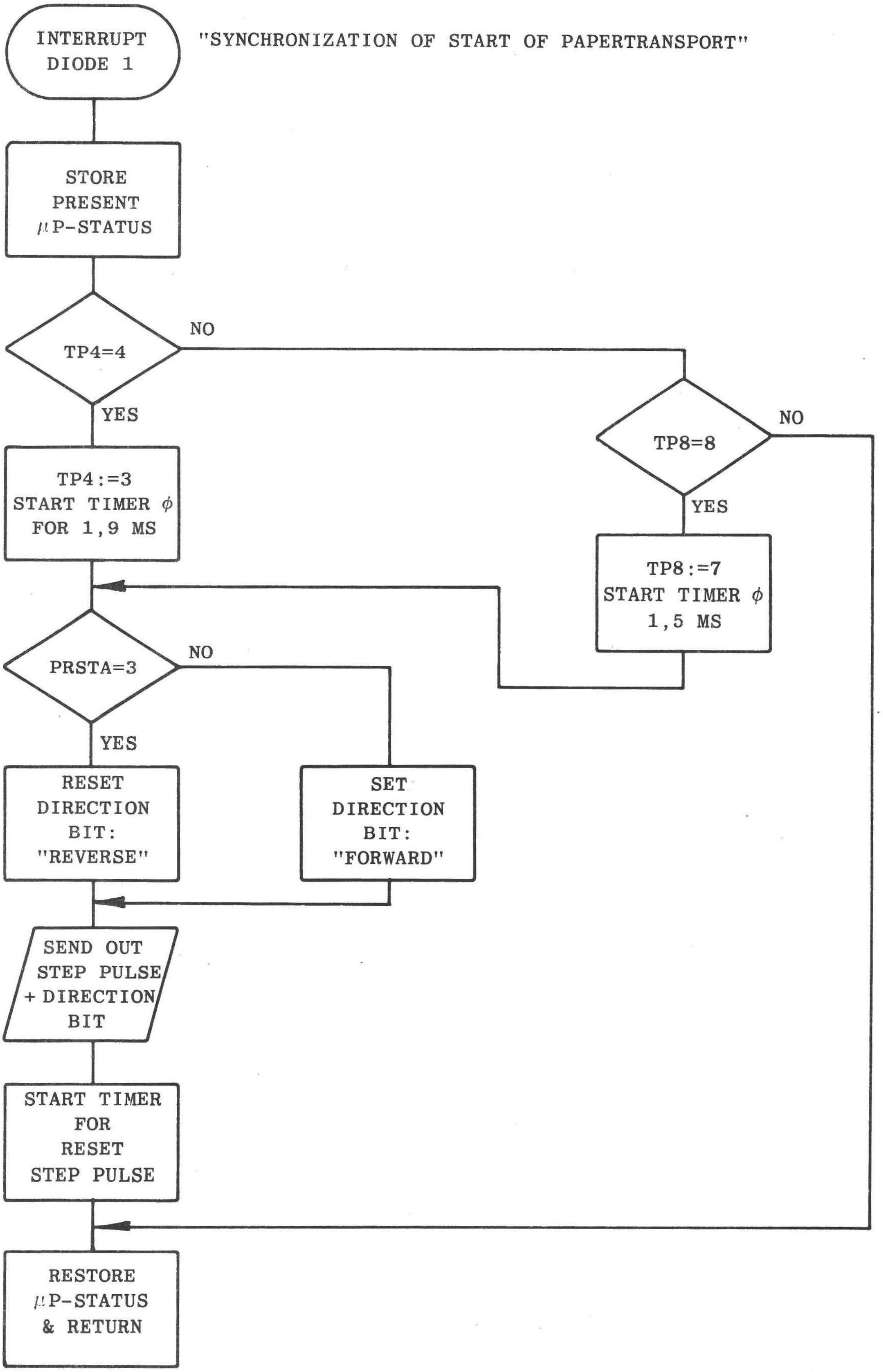
Braille lineprinter driver - Flowchart 3.



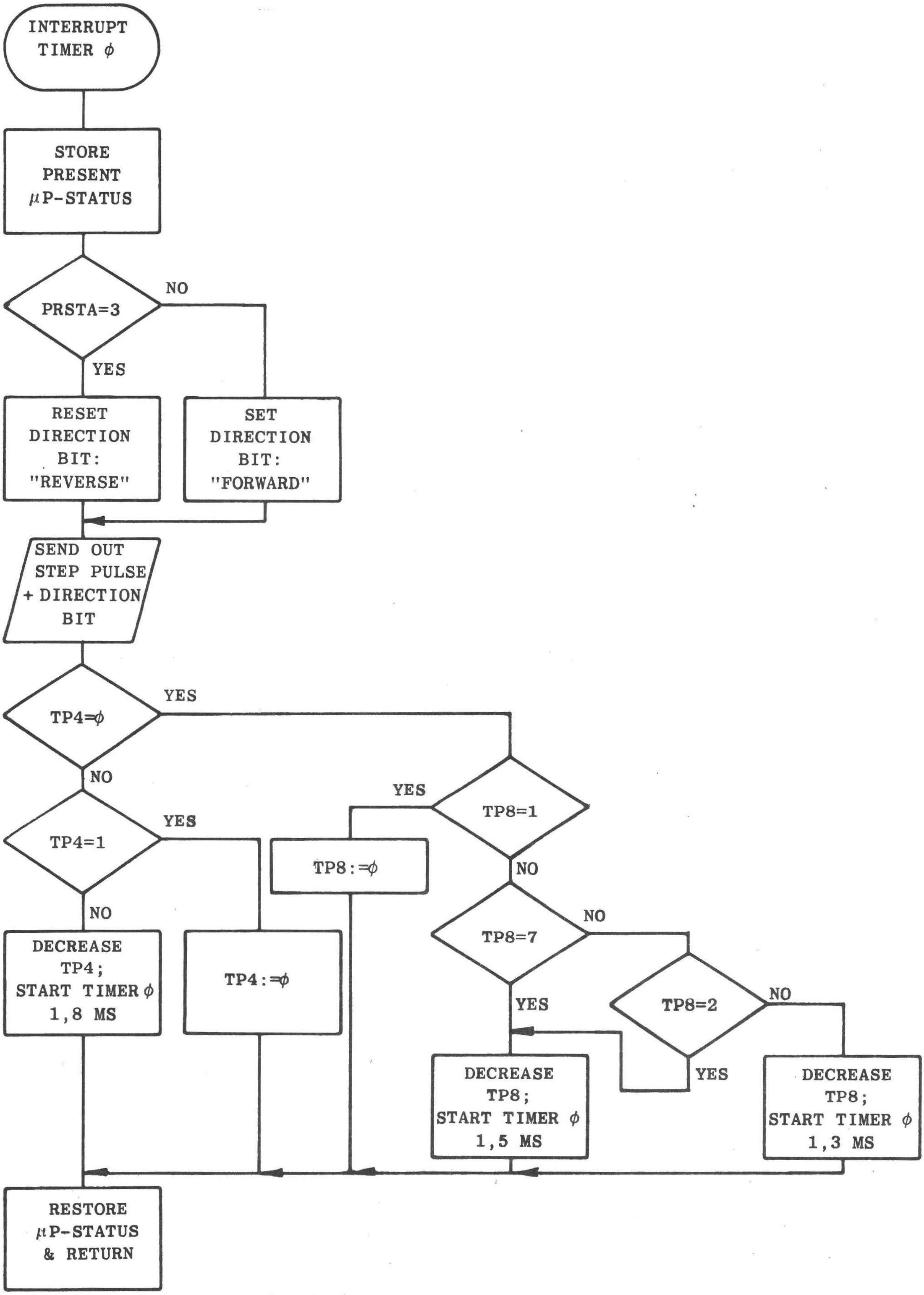
Braille lineprinter driver - Flowchart 4.



Braille lineprinter driver - Flowchart 5.

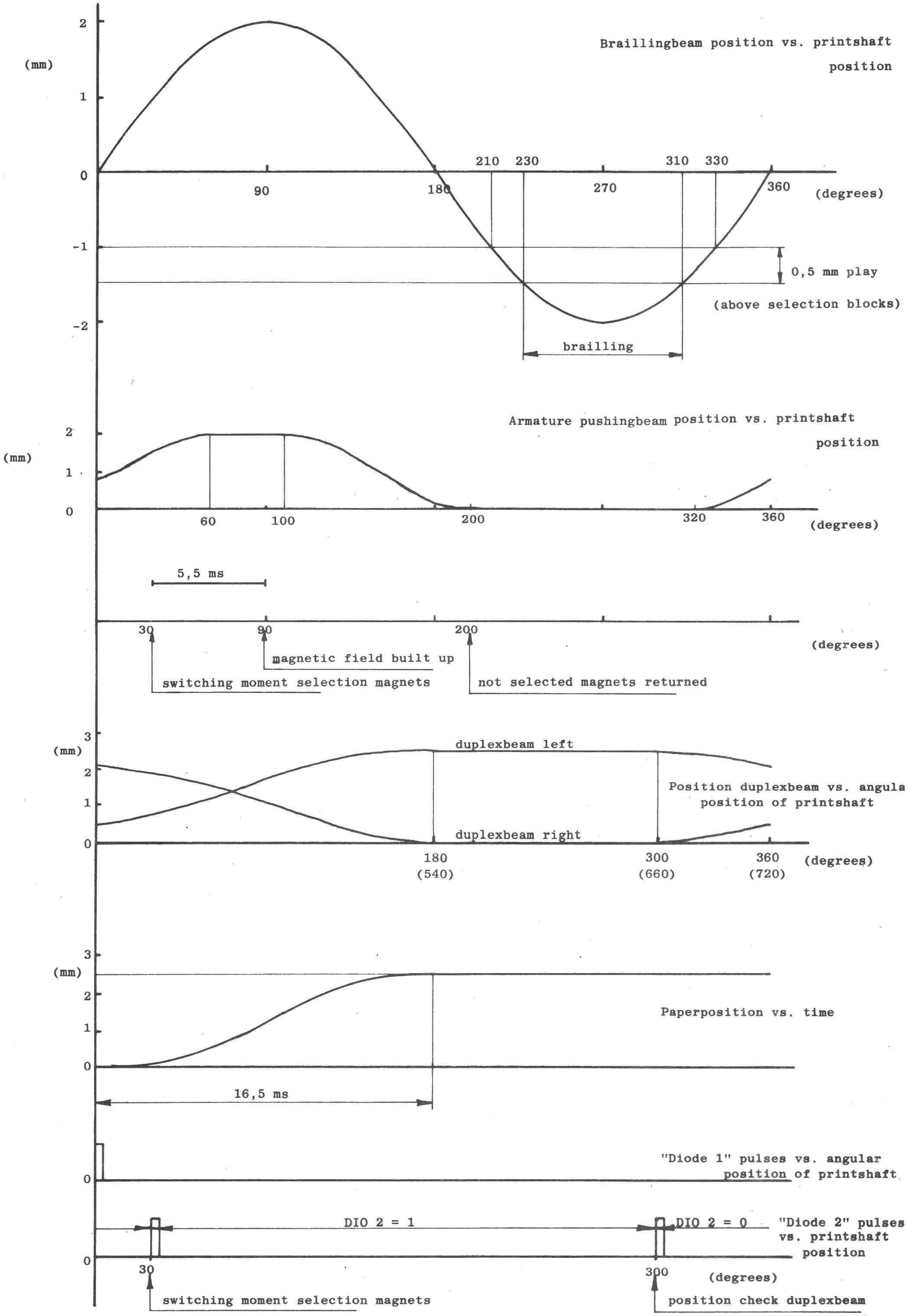


Braille lineprinter driver - Flowchart 6.



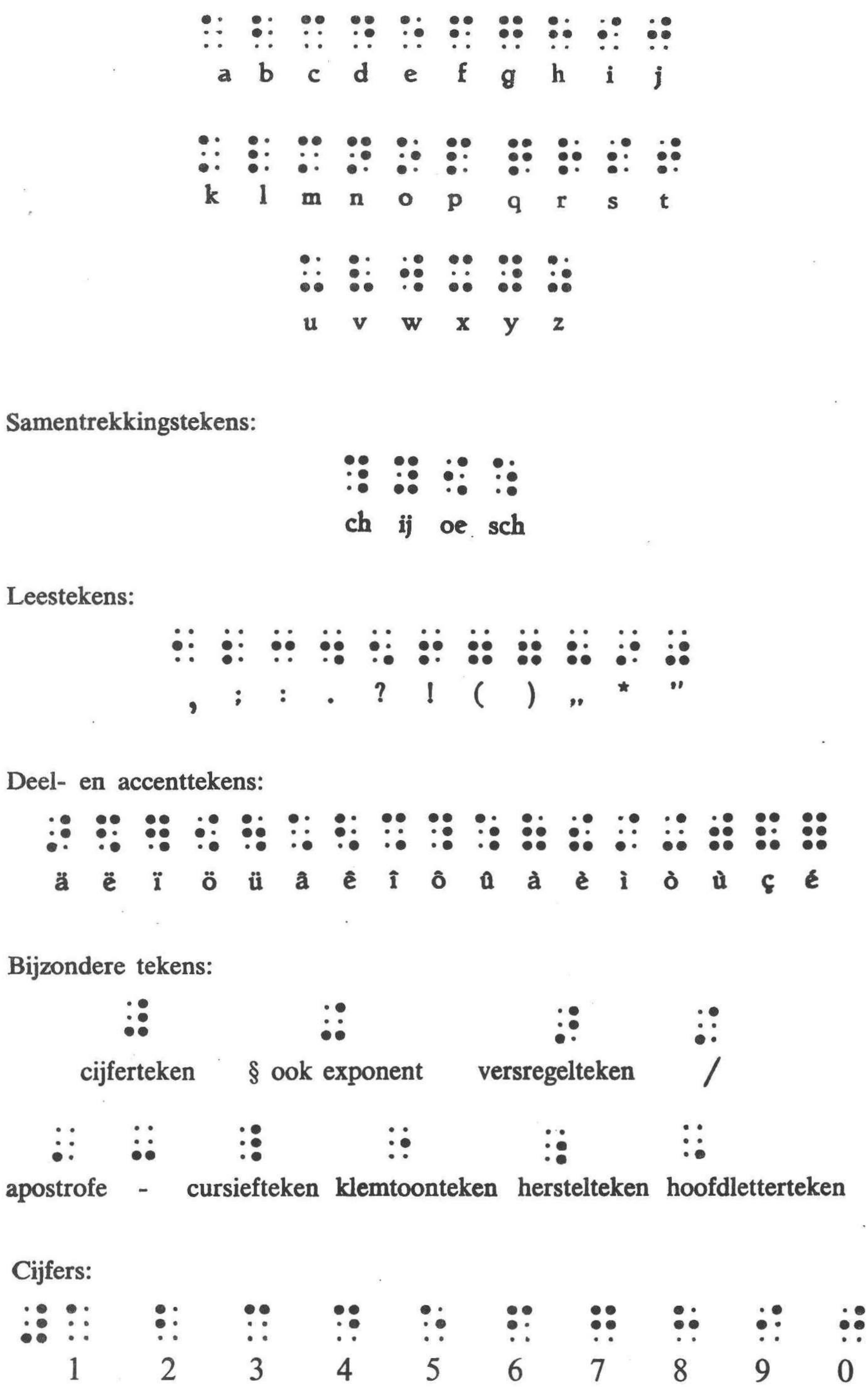
Braille lineprinter driver - Flowchart 7.

8.4. <u>Lineprinter timing diagram</u>.



Displacement - Time diagrams braille lineprinter.

8.5. The braille code for the Dutch language.



8.6. Calculation of the deformations that occur in the lineprinter during brailling.

The brailling of a cycle with all forty dots selected, produces the largest deformations in the brailling frame. The parts that show the largest deformation are the main printer shaft (partnr 3), the brailling beam (partnr 6, 8 and 15) and the fixed support beam (partnr 47), because they are subject to bending.

This means that the dotheight depends on the number of braille dots that are printed simultaneously. Deformation of the main printer shaft decreases the height at the same rate for all dots that are printed during one cycle. Bending of the brailling beam and of the support beam decreases the height of the dots in the middle of a line mostly.

An estimate of the amount of height reduction caused by these deformations can be obtained as follows:

If all forty selectionblocks are in their active position the total force acting on the brailling beam equals 800 Newtons. This force is evenly distributed over both rollers.

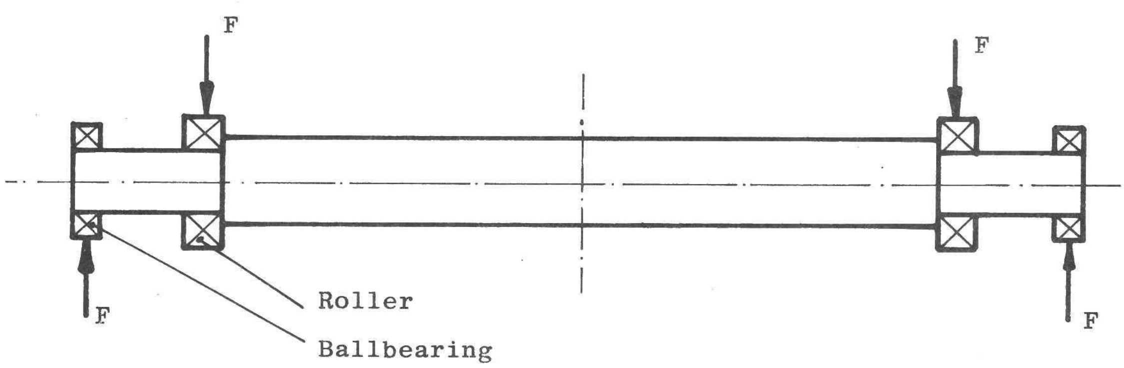


FIGURE 8.6.1

Forces acting on the printer main shaft.

Because the distribution of the load is symmetrical with respect to the middle of the main printer shaft, the relative displacement of the points of application of the forces F can be calculated as follows:

The shaft is thought to be clamped in its middle and only one half is considered:

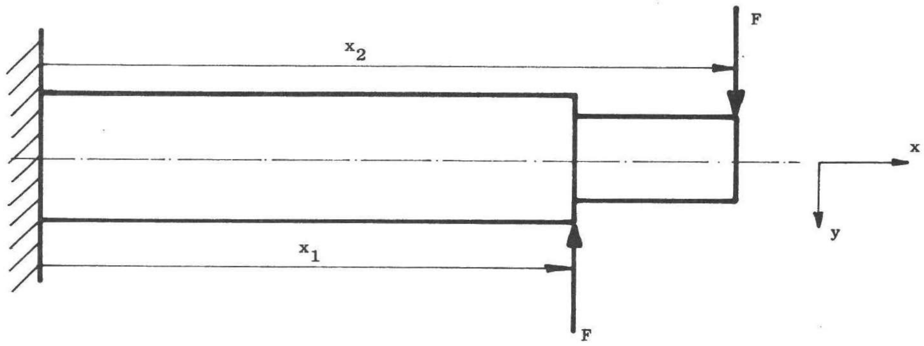


FIGURE 8.6.2

Forces acting on printer main shaft.

For $0 < x < x_1$: $B = EI_1$

$x_1 < x < x_2$: $B = EI_2$, in which

B = bending stiffness (Nmm^2)

E = Youngs modulus (N/mm^2)

I = equatorial moment of inertia (mm^4).

Taking the positive Y-axis downwards:

$$y(x_2)-y(x_1) = \frac{F(x_2-x_1)^3}{3EI_2} + \frac{F(x_2-x_1)^2 \cdot x_1}{EI_1}, \qquad (8.6.1)$$

with $F = 400$ N

$x_1 = 145$ mm

$x_2 = 190$ mm

$B_1 = 2{,}1 \cdot 10^5 \cdot \frac{\pi}{64} \cdot 35^4 = 1{,}55 \cdot 10^{10}$ Nmm^2

$B_2 = 2{,}1 \cdot 10^5 \cdot \frac{\pi}{64} \cdot 24^4 = 3{,}42 \cdot 10^9$ Nmm^2,

this yields: $y(x_2)-y(x_1) = 11{,}1$ μm.

So during brailling of 40 dots the relative position of rollers and main shaft bearings changes 11 μm in the direction of the working lines of the forces F.

The loads on the brailling beam are sketched in the next figure:

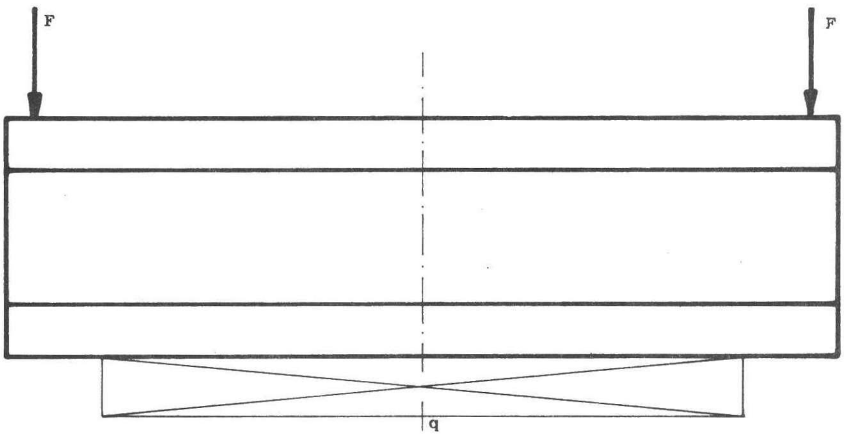


FIGURE 8.6.3
Loads acting on brailling beam.

The two forces F are exerted by the rollers on the brailling beam, the uniform load q is a model for the forty forces exerted by the brailling pins. While all loads are symmetrical with respect to the middle of the beam, again the beam can be thought clamped in the middle because the rotation of the beam there is zero.

The deflection of the end of the brailling beam with respect to its middle is given by:

$$y(x_2) = \frac{-qx_1^4}{3EI} + \frac{F(x_2-x_1)x_1^2}{EI} + \frac{Fx_1^3}{3EI} + \frac{F(x_2-x_1)^3}{3EI} - \frac{qx_1^3(x_2-x_1)}{6EI} +$$

$$\frac{F(x_2-x_1)^2x_1}{EI}, \qquad (8.6.2)$$

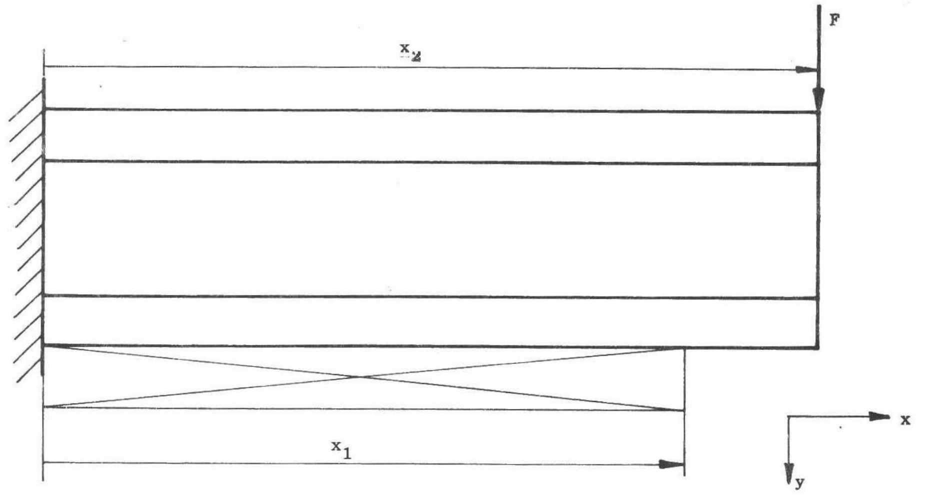


FIGURE 8.6.4

Loads acting on brailling-beam.

with: $F = 400$ N

$x_1 = 120$ mm

$x_2 = 145$ mm

$q = 3{,}33$ N/mm

$B = 1{,}27 \cdot 10^{10}$ Nmm^2, this yields:

$y(x_2) = 23$ µm.

Using the same model for the calculation of the maximum deflection of the fixed support beam, with

$x_1 = 120$ mm

$x_2 = 190$ mm

$q = 3{,}33$ N/mm

$B = 1{,}6 \cdot 10^{11}$ Nmm^2, this yields:

$y(x_2) = 4{,}8$ µm.

So the maximum reduction of the dotheight amounts to 4.8 + 23.0 + 11.1 = 33.9 μm. This remains well below the limit of 50 μm that was set in the specifications.

8.7. Selection of steppermotor.

The usual procedure that steppermotor manufacturers suggest for the selection of their motors, is to assume that the steppermotor can deliver a constant torque over its usefull speed range. Normally electric steppermotors have a torque versus speed characteristic in which the torque decreases with increasing speed (because of the increasing influence of coil inductances with higher switching rates), so the value of the torque that appears in the calculations is the torque the motor can deliver at the highest speed that occurs during the movement.

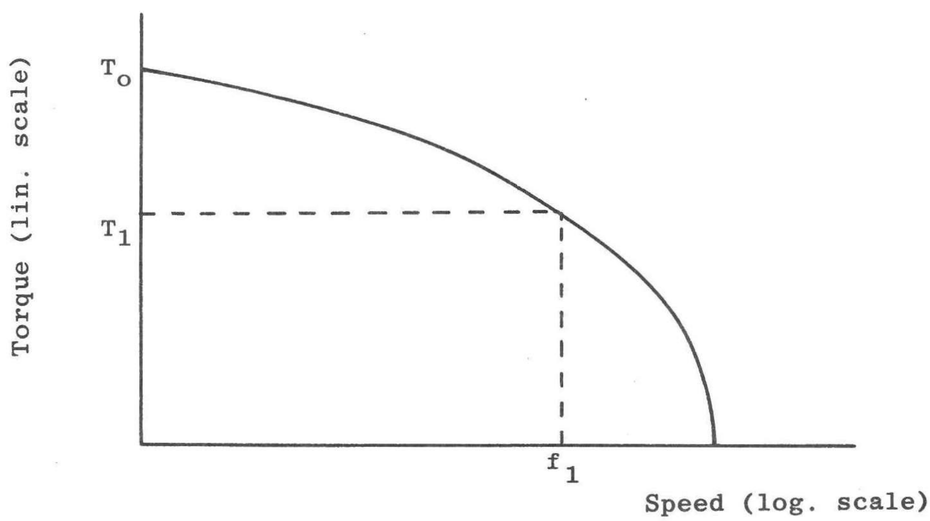


FIGURE 8.7.1

General performance curve for an electric steppermotor.

If for instance f_1 is the highest frequency that occurs during the movement of the steppermotor (the movement being calculated assuming a constant acceleration and a constant deceleration), then T_1 is the torque used in the calculation of acceleration and deceleration times. This means that during acceleration and deceleration a part of the steppermotor power is not accounted for in this method of calculation. If the movement that the steppermotor must generate, consists only of deceleration or acceleration of the load, this calculation method is rather conservative.

If the load does not vary much and one has the possibility to optimize the pulse sequence to the motor empirically to avoid resonance regions and overshoot at the end of the movement, a calculation method may be adopted that describes the motor behaviour more accurately. Optimizing the pulse sequence to the motor leads to a motor operating very close to the maximum torque it can deliver over its entire speed range. In this case the motor behaviour can be predicted by using the data its manufacturer supplies in the steppermotor characteristic. Usually the steppermotor performance characteristic is determined by running the motor at a certain speed and then increasing its loading torque until the motor starts losing steps. This procedure is repeated for different speeds and so a torque-speed curve is plotted. This implies that these data were taken when the rotor frequency of the steppermotor was equal to the statorfield frequency or in other words, the rotor was running synchronous with the statorfield. If a steppermotor is loaded with a larger torque than the torque from the performance curve at the speed at which the motor is running, the maximum phase lag between statorfield and rotorfield will be reached and the rotor will fall out of synchronisation with the statorfield. For all smaller values of the loading torque synchronisation is assured (at this speed).

Assuming that the motor torque decreases linear with the motor speed, this torque can be described as:

$$T(t) = T_o - k\dot{\varphi}(t), \tag{8.7.1}$$

in which: $T(t)$ = steppermotor torque (Nm)

T_o = steppermotor starting torque (Nm)

k = steppermotor damping constant $(\frac{\text{Nms}}{\text{rad}})$

$\dot{\varphi}(t)$ = steppermotor speed $(\frac{\text{rad}}{\text{s}})$

This relation is plotted in the steppermotor torque speed characteristic (Fig. 8.7.2 with lin-log scales and Fig. 8.7.3 with lin-lin scales) to show how these two compare for the Berger RDM 569/50 steppermotor.

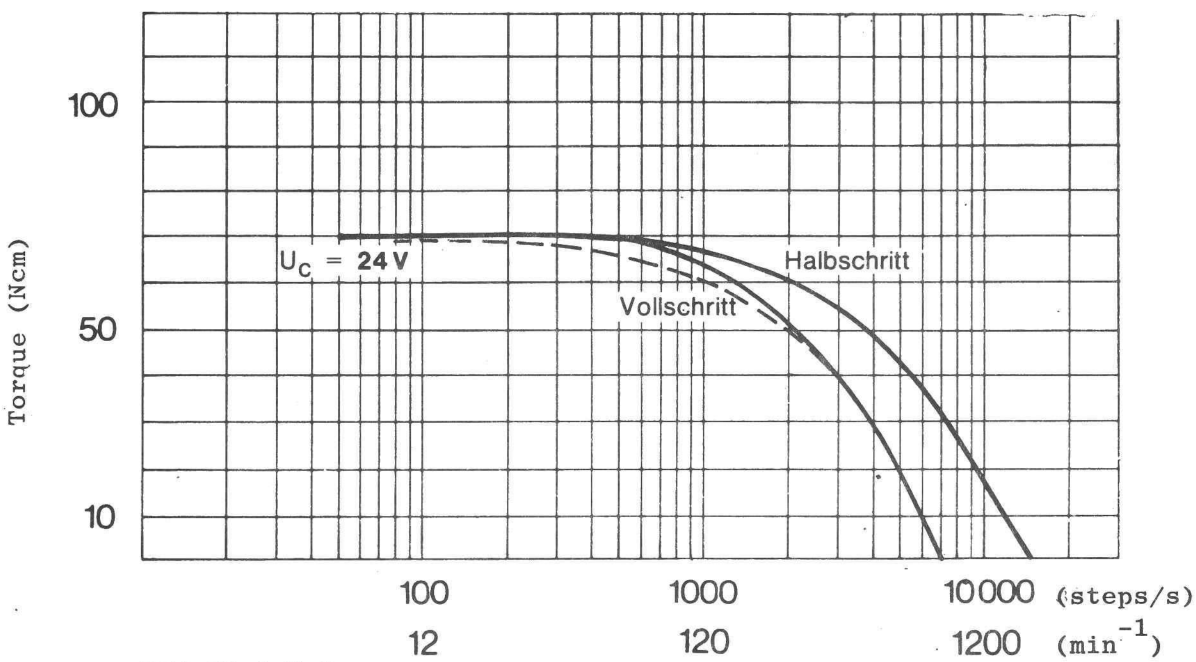


FIGURE 8.7.2

Relation between the actual steppermotor performance and the performance that is assumed in the calculation.

——— *actual performance acc. to manufacturer*

– – – *assumed performance in calculations*

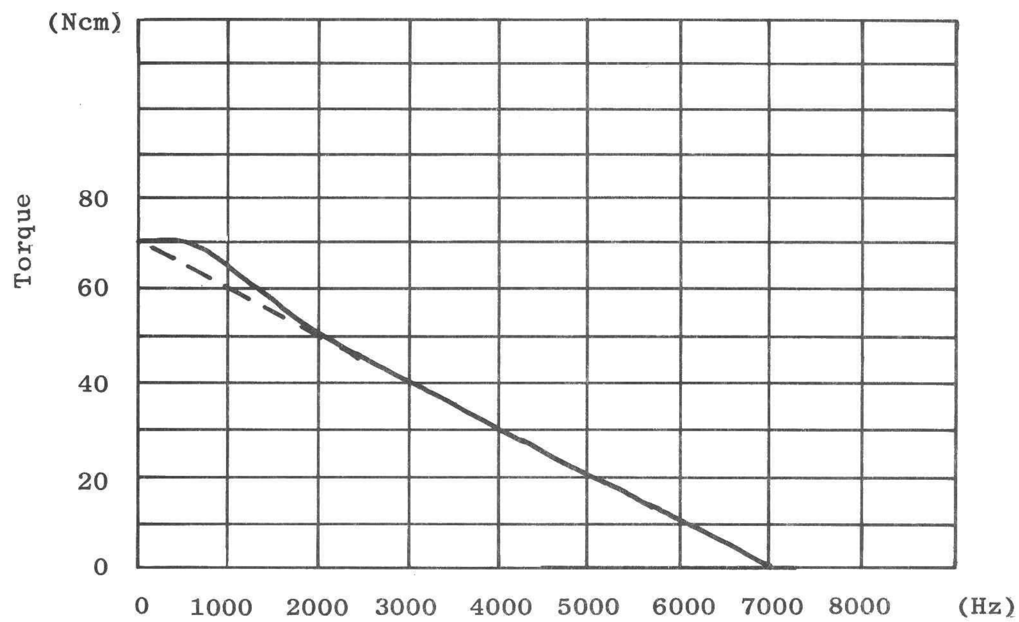


FIGURE 8.7.3

Relation between the actual steppermotor performance and the performance that is assumed in the calculations (on lin. scales).

——— *actual performance acc. to manufacturer*

– – – *assumed performance in calculations*

Combining this with

$$T(t) = J\ddot{\varphi}(t) , \tag{8.7.2}$$

in which J = inertia of steppermotor rotor and load (kgm^2)
$\ddot{\varphi}(t)$ = angular acceleration of rotor (rad/s^2)

this yields:

$$J\ddot{\varphi}(t) + k\dot{\varphi}(t) = T_o \tag{8.7.3}$$

The solution for this differential equation for $\varphi(t)$ can be given as:

$$\varphi(t) = c_1 \frac{J^2}{k^2} e^{-\frac{k}{J}t} + \frac{T_o}{k} t + c_2 \tag{8.7.4}$$

From the boundary conditions for t=0:

$\varphi(0) = 0$ and
$\dot{\varphi}(0) = 0,$

it can be concluded that

$$c_1 = \frac{T_o}{J} \quad \text{and} \quad c_2 = -\frac{T_o J}{k^2} .$$

So the expression for $\varphi(t)$ looks like:

$$\varphi(t) = \frac{T_o}{k}(t-\tau+\tau e^{-t/\tau}), \tag{8.7.5}$$

with $\tau = \frac{J}{k}$.

This expression is valid for the accelerating part of the rotor movement. Let us assume that this acceleration stops at $t=t_o$. From this time on the motor is decelerated with a torque:

$$T(t) = -T_o + k\dot{\varphi}(t) \qquad \text{for} \qquad t > t_o, \qquad \text{and} \qquad \dot{\varphi}(t) > 0. \tag{8.7.6}$$

Again combining this with $T(t) = J\ddot{\varphi}(t)$ and solving the resulting differential equation for $\varphi(t)$ with boundary conditions for $t = t_o$:

$$\varphi(t_o) = \frac{T_o}{k}(t_o-\tau+\tau e^{-t_o/\tau}) \quad \text{and}$$

$$\dot{\varphi}(t_o) = \frac{T_o}{k}(1-e^{-t_o/\tau})$$

this yields:

$$\varphi(t) = \frac{T_o}{k}(-\tau e^{(t-2t_o)/\tau}+t-\tau+2\tau e^{-t_o/\tau}) \quad \text{for} \quad t > t_o \tag{8.7.7}$$

This equation is valid as long as $\dot{\varphi}(t) > 0$. It can be calculated from this equation that $\dot{\varphi}(t) = 0$ for $t = 2\,t_o$, so the complete condition under which the equation is valid, is $t_o < t < 2t_o$.

From the last equation one can derive that $\varphi(2t_o) = 2\varphi(t_o)$. So it is sufficient to check whether the steppermotor can drive its load over half the required angle during half of the available time, using the simpler equation:

$$\varphi(t) = \frac{T_o}{k}(t-\tau+\tau e^{-t/\tau}) \; .$$

An important aspect of the above calculations is the assumption that the motor is braked with the same torque-speed relation that is used during acceleration. If friction plays an important role during the movement, the torque available for acceleration of the load is smaller than the available decelerating or braking torque, so the necessary times to accelerate till a certain speed and to decelerate from the same speed till zero are different. In this case these assumptions are not valid. However when the friction torque is no more than 10% of the starting torque of the steppermotor, the total increment in time necessary to reach the same rotor position when friction is present, compared to the case without friction, is no more than 1,5%. The necessary time to reach a certain position depends not only on the amount of friction, but also of course on the required position itself. Table 8.7.4 gives the relationship between these times, for six different step sizes and four different values of the friction. The step sizes are based on the angles the rotor can reach without friction. With friction ($\alpha > 0$) the necessary times to reach the same step size are of course larger (columns 3, 4 and 5). The four last columns of the table give information about the position of the point t_o: The moment when acceleration should stop and deceleration should start, in order to reach the end position with velocity zero. In this table α is defined as:

$$\alpha = \frac{T_f}{T_o} , \tag{8.7.8}$$

with T_f = friction torque (constant) (Nm)

T_o = steppermotor starting torque (Nm).

TABLE 8.7.4

Relation between the total step angle (φ_{stop}), the necessary time to reach this angle (t_{stop}) and the acceleration time (t_o) in the presence of friction.

$\frac{\varphi_{stop} \cdot k}{T_o \cdot \tau}$	$\frac{t_{stop}}{\tau}$				$\frac{t_o}{\tau}$			
	α=0	α=0,1	α=0,2	α=0,3	α=0	α=0,1	α=0,2	α=0,3
0,21	1	1,01	1,03	1,02	0,5	0,57	0,65	0,70
0,73	2	2,02	2,06	2,16	1,0	1,17	1,37	1,60
1,45	3	3,04	3,14	3,33	1,5	1,87	2,24	2,64
2,26	4	4,05	4,23	4,55	2,0	2,63	3,21	3,80
3,16	5	5,07	5,45	5,85	2,5	3,52	4,38	5,08
4,01	6	6,08	6,46	7,07	3,0	4,42	5,37	6,30

Applying these calculations to the case under consideration neglecting the influence of friction because the friction torque is smaller than 10% of the steppermotor starting torque, using:

$$\varphi(t) = \frac{T_o}{k} (t-\tau+\tau e^{-t/\tau}),$$

with T_o = 0,7 Nm,

$k = 8.10^{-3} \frac{\text{Nms}}{\text{rad}}$,

$\tau = \frac{J}{k} = 10^{-2}$ s,

φ = 0,13 rad,

the accompanying value for t is 6 ms. So with the "Berger RDM 569/50" steppermotor the total step can be made in app. 12 ms.

(In the conventional calculation the motor would make the total step in 15 ms.)

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SUMMARY

This thesis deals with the design of a braille lineprinter that is capable of producing braille on paper with the weight that is normally used for braille production (typ. 160 grams/m^2) and on lighter grade paper, with a maximum speed of five lines per second. The designed lineprinter employs an embossing principle that is different from the principle that is used up till now in other equipment for braille production; this results in a more uniform height of the produced brailledots, offering better quality braille.

The lineprinter is microprocessor controlled and the thesis includes a description of both control hardware and software for operation of the printer as a stand-alone device with a "FACIT-SP 1" interface, the standard "FACIT" interface for parallel data transfer.

Analysis of brailling principles used in other equipment shows that all these machines operate by controlling the force that produces the brailledot. This can cause large variations in the resulting brailledot height. In the presented printer not the force producing the brailledot is controlled, but rather the resulting brailledot height itself. As a basis for all fundamental decisions concerning the design, a separation is made between function groups that convert energy and function groups that convert information. This leads to a printer with both a higher total efficiency and a better accessibility for service purposes.

All translating parts in the lineprinter have bearing systems that employ elasticly deflecting leafsprings in order to attain a cheap way of guiding the movement, insensitive to paperdust and showing no wear. To enable the production of small numbers of the printer all suitable parts are designed such that they can be manufactured by metal etching. The lineprinter is equiped to use fanfold pinfeed paper with a maximum width of 14 inches. The paper drive system use two papertractors that are driven by an electric steppermotor.

SAMENVATTING.

Dit proefontwerp beschrijft een brailleregeldrukker die in staat is braille te produceren op het normaal gangbare papier voor brailleproduktie (ca 160 gram/m^2) en op lichter papier, met een maximale snelheid van vijf regels per seconde. De ontworpen regeldrukker gebruikt een brailleer-principe dat afwijkt van hetgeen tot nu toe gebruikelijk is in andere apparatuur voor brailleproduktie; dit resulteert in een kleinere variatie in de geproduceerde braillepunthoogte, hetgeen een betere kwaliteit braille betekent.
Een analyse van de brailleerprincipes die in andere apparatuur worden gebruikt toont aan, dat al deze apparaten de kracht regelen die uiteindelijk de braillepunt oplevert. Dit kan leiden tot grote variaties in de geproduceerde punthoogte. In de hier gepresenteerde regeldrukker wordt niet deze kracht geregeld maar de resulterende braillepunthoogte zelf.
Als basis voor alle fundamentele beslissingen die het ontwerp betreffen, wordt een scheiding gemaakt tussen functiegroepen die energie omzetten en functiegroepen die informatie omzetten. Dit leidt tot de constructie van een regeldrukker met een hoger rendement die daardoor sneller kan werken.
Het apparaat is zoveel mogelijk modulair opgebouwd teneinde de toegankelijkheid voor servicedoeleinden te verbeteren. Bovendien is geprobeerd zoveel mogelijk gebruik te maken van normaal commercieel verkrijgbare onderdelen. Om juist de produktie in kleine aantallen mogelijk te maken van deze regeldrukker, zijn alle daarvoor in aanmerking komende onderdelen zodanig ontworpen dat ze vervaardigd kunnen worden door middel van een etsprocédé
Alle heen en weergaande delen hebben lageringen die elastisch uitbuigende bladveren benutten teneinde een goedkope lagering te realiseren, ongevoelig voor papierstof en slijtage.

De regeldrukker wordt bestuurd met behulp van een ingebouwde microprocessor; het proefontwerp bevat tevens een beschrijving van de voor deze besturing benodigde elektronische componenten en het besturingsprogramma. Dit programma bestuurt alle functies in de regeldrukker zelf en regelt de informatie-overdracht naar de drukker; bovendien wordt een hulpmiddel geboden om het storingzoeken te vergemakkelijken.
De regeldrukker is erop ontworpen om kettingformulieren met randperforatie te gebruiken met een maximale breedte van 14 inch. Het hiervoor ingerichte papiertransportsysteem maakt gebruik van twee tractoren die worden aangedreven met behulp van een elektrische stappenmotor.

STELLINGEN BEHOREND BIJ HET PROEFONTWERP:

"DESIGN OF A BRAILLE LINEPRINTER".

1. Het toenemend gebruik van beeldschermen voor de presentatie van alfanumerieke informatie betekent een extra handicap voor blinden en slechtzienden die in hun beroep dit soort informatie moeten verwerken.

2. Wanneer een braille equivalent van het beeldscherm voor tekstverwerking ter beschikking komt, kan de invoering van "Teletekst" en "Viewdata" ook voor blinden en slechtzienden een uitbreiding van hun informatiepakket betekenen.

3. Even belangrijk als de verkrijgbaarheid van nieuwe technische hulpmiddelen voor gehandicapten is een adequate service-mogelijkheid bij eventuele defecten.

4. Een besparing op elektrische energie is te bereiken door ervan uit te gaan dat het verlichtingsniveau in werkruimtes, dat benodigd is voor de aldaar plaats vindende werkzaamheden, niet in de gehele ruimte hoeft te heersen, maar alleen ter plaatse van de werkvlakken.

5. Een effectievere methode van brandstofbesparing dan de (her) invoering van een autoloze zondag is haalbaar door de afgifte van nieuwe kentekenbewijzen afhankelijk te stellen van een voor ieder voertuigtype vast te stellen maximum brandstofverbruik, dit gebaseerd op standaard testmethoden.

6. De introductie van programmeerbare elektronische besturingen vergemakkelijkt het gebruik van elektronische besturingen door diegenen die geen specifieke elektronicakennis bezitten.

7. Juist in de ontwikkelingsfase van het mechanische deel van een elektronisch bestuurd apparaat kan een programmeerbare elektronische besturing, door de inherente grotere flexibiliteit, zijn vruchten afwerpen.

8. Ontwerpen is een groepsactiviteit bij uitstek.

9. Bij het berekenen van bladveren die vervaardigd zullen worden uit koud gewalst verenstaal, dient men ermee te rekenen dat de elasticiteitsmodulus loodrecht op de walsrichting tot 20% groter kan zijn dan in de walsrichting.

10. Een logisch vervolg op de eventuele invoering van een z.g. lawaaiheffing op personenauto's welke wordt geïnd via een verhoging van de motorrijtuigenbelasting, is de invoering van een huurverhoging voor de bewoners van gehorige flats.