CERN 73-6
Laboratory II
Control Group.
24 May 1973

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

TWO DEVICES FOR OPERATOR INTERACTION IN THE CENTRAL CONTROL OF THE NEW CERN ACCELERATOR

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CONTENTS

1. INTRODUCTION

The Proton Synchrotron currently being built by CERN (the SPS) will be controlled centrally from three control desks, each with its own mini-computer. Only a few knobs and switches must control all the many thousands of digital and analog parameters of the accelerator, and an operator will watch the machine on at most half-a-dozen displays. This might be considered as the multiplexing of the operator and his interface over all the subsystems of the accelerator, and carries with it all the disadvantages and advantages of multiplex systems in general.

The disadvantage is that the method is certainly clumsy when compared with control rooms in which all variables are constantly accessible for control and observation. The operator will often experience a time-lag before the limited facilities available to him can be used to control or monitor some subsystem.

An advantage of the new form of control, however, is that since there are so few controls and displays, they may be made more elaborate and powerful. Two devices are described in this paper which it is hoped will play an important part in control from the desks.

The first of these devices is the touch screen. This is effectively a panel having a number of buttons with legends on them. The buttons are input devices to the computer, and the legends can be written by computer. This makes it possible for the operator to do a look-up in a very large table with only a few buttons, by presenting him successively with choices which depend on his previous decisions.

The second device is a knob with feedback from the computer. This makes it practicable to use one knob, at will, as an incremental encoder, a multiposition switch, or as a velocity control with spring-return to zero.

Both devices have been interfaced to the CAMAC system which is being used throughout the SPS control project. They are easily accessed by users of the interpretive control language, and can therefore be used to construct quite sophisticated interactive systems with little effort.

2. THE TOUCH SCREEN

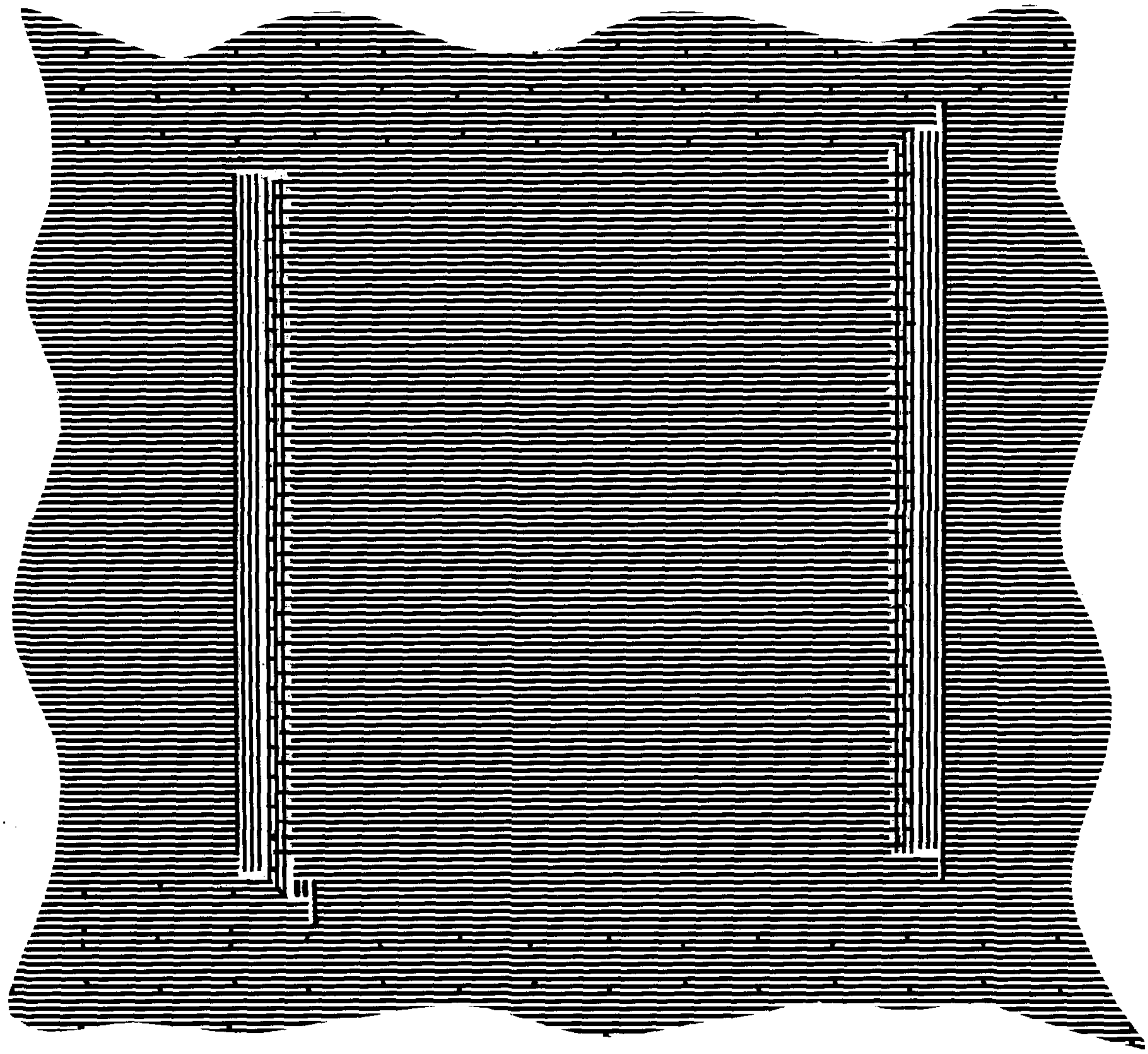
2.1 Introductory

This device is essentially a panel consisting of push-buttons connected to the computer, each button having a legend written on it, which can be changed at will under computer control. The advantages of such a device are obvious. Not only can a few buttons perform in turn the functions of an arbitrarily large number, but there is no need to confuse the operator with the presence of hundreds of buttons that are irrelevant in the current context.

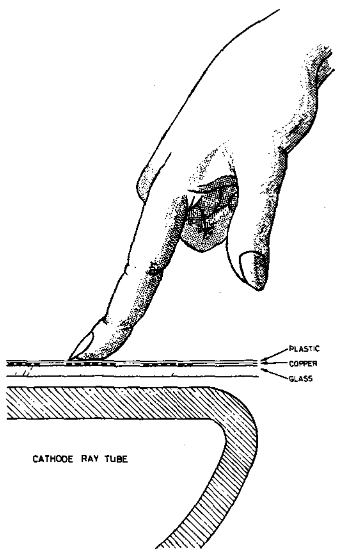
2.2 Button legends

In the current state of technology, it seems that the only way to write the legends is with a CRT. All other methods produce characters which are too large to allow a useful message to be written in the area of a button, or are impractical for other reasons.

Having drawn the "buttons" and their legends on the face of a CRT, we are now left with the problem of detecting, in the computer, which button has been selected.



a) Area around one touch-button (enlargement about six times)



b) Touch-button in use

Fig. 1

2.3 Physical principle employed

After consideration of the physical principles which could be applied, it was decided to use electrical capacity. Section 2.7 gives a short list of practicable physical principles. The device which has been constructed uses a set of capacitors, etched into a film of copper on a sheet of glass and made of line elements sufficiently thin and well separated to be effectively invisible. Each capacitor is so constructed that the proximity of a flat conductor, such as the surface of a finger, increases its capacity by a fairly large factor. Figure 1a shows the form of a single capacitor. Figure 1b shows a touch-button in use.

The leads which connect each capacitor to its detecting circuit also have capacity, but the proportional increase due to bringing a finger near these is very small.

Actual contact between a finger and the capacitor is prevented by a thin sheet of plastic. Work is still in progress on the production of a thin transparent cover which is integral with the glass sheet and therefore more durable.

Interference between adjacent capacitors is prevented by the use of an earthed pattern covering all unused parts of the screen. Capacity between individual elements and earth is reduced by interposing unconnected wires. All leads which have important functions are in triplicate with frequent cross-connections, to prevent an isolated defect of manufacture from breaking any important circuit. (A close study of Fig. 1a will reveal all these features.)

Fig. 2 The touch-screen

2.4 The screen

The actual screen used was made by normal printed circuit techniques. Figure 2 shows that the screen is for all practical purposes transparent. The fact that the conductors comprising the capacitors and leads are 80 μ wide and are separated by the same distance, meant that exceptional care had to be taken with the process, and especially with the subsequent removal of the photo-resist, but the screen was produced successfully with careful application of the techniques normally used in the printed circuit shop.

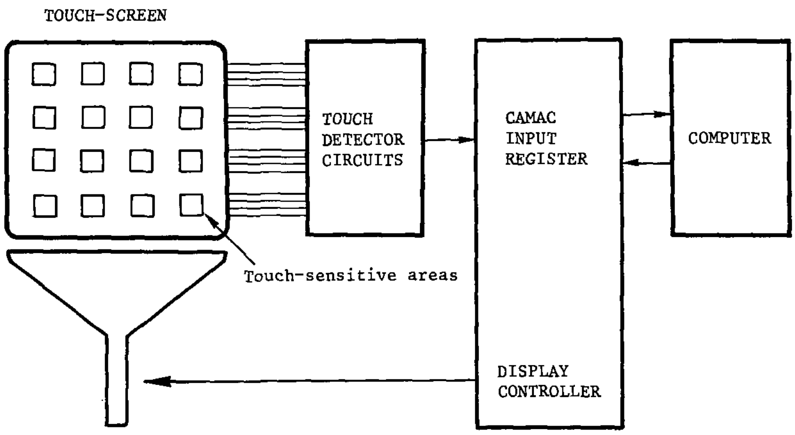
The final screen was thinly gold-plated as a precaution against corrosion. To get the original copper layer on glass was a slightly harder problem. Vacuum deposition was tried, but it proved impossible to get reliable adherence by means of this method. Ion sputtering, however, gave better results, and this process was chosen. Borosilicate glass was originally used as a protection against thermal shocks incurred during the process, but this turned out to be unnecessary.

By ensuring scrupulous cleanliness of the glass, and depositing the copper slowly, sufficiently strong adherence of the copper was obtained for soldered connections to be feasible. (Low-temperature soldering at 150°C is used, and the work must be done quickly.) Approximately 10 μ of copper were deposited over a period of one hour.

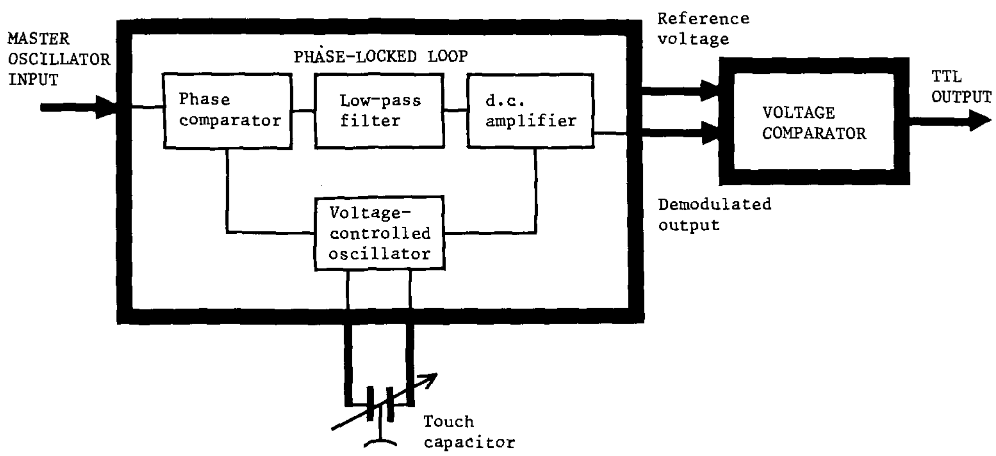
2.5 Detecting the change in capacity

The capacitors printed on the touch-screen have a capacity, including fairly long leads, of about 200 pF, rising by about 10% when a finger-tip is brought into close proximity.

Obvious methods of detecting changes in capacity are the upsetting of a balanced bridge network and the detuning of a resonant circuit. Both these methods are liable to be upset by extraneous voltage spikes and by thermal and other drifts. The chosen method is to use a phase-locked oscillator circuit which has recently become available as a single integrated circuit chip (Signetics NE565K) [1]. One of these circuits is used as a reference oscillator for all the buttons, and each button has a similar circuit, controlled by the capacity of the button. The oscillator, running at 120 kHz, locks in frequency to the reference oscillator, and a change in capacity causes only the phase, but not the frequency, to alter. A change in the error-correcting voltage is detected by discrimination against a reference voltage, using an integrated discriminator chip (National LM311N). Figures 3a and 3b describe the principle, and Figure 4 shows the circuit as it is actually being used. Both the over-all

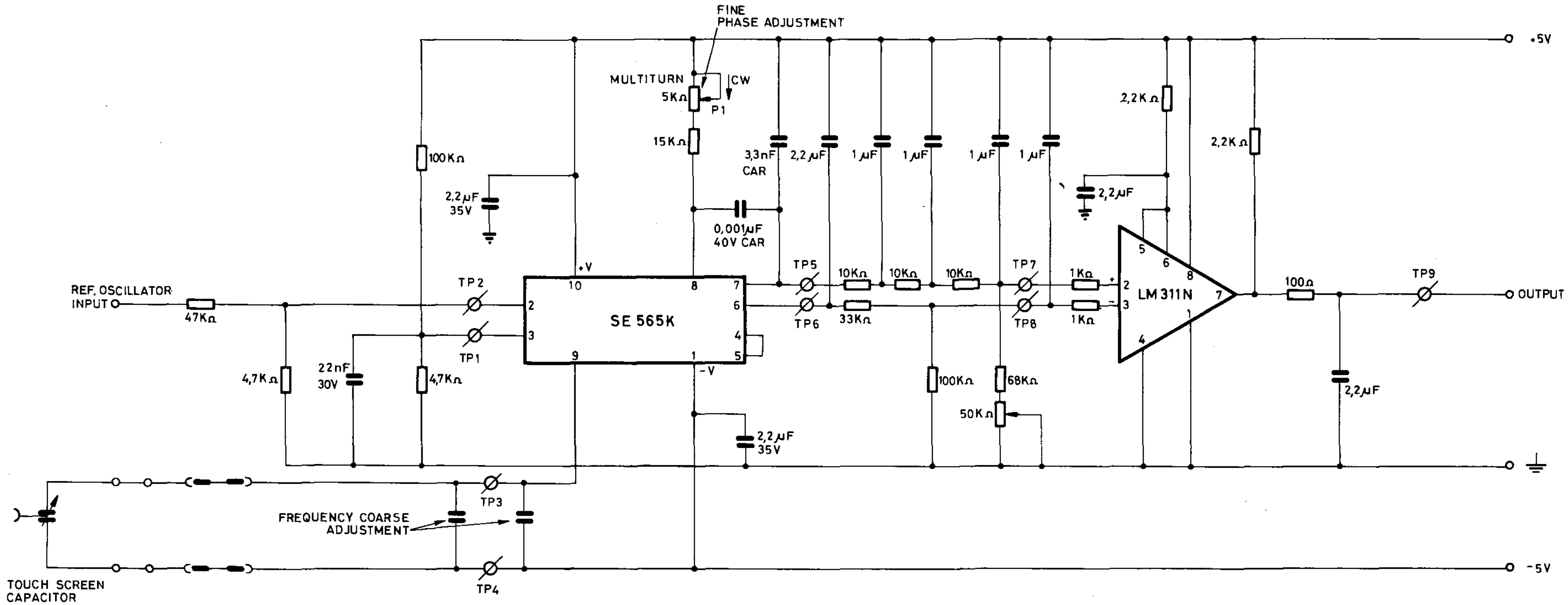


a) Over-all connections in the touch-screen system



b) Detection process for one button

Fig. 3



TP : TEST POINT

Fig. 4 Detector circuit for one button

sensitivity and the sensitivity of each button are adjustable. The circuit has a rejection to amplitude transients of better than 40 dB, and the thermal stability using commercial, low-grade components appears to be adequate, because it is unaffected by drifts common to both oscillators.

Figure 5 is a photograph of the circuit board actually used. It is probably worth pointing out that while the use of what is intrinsically an elaborate circuit for detection may seem extravagant, the availability of the phase-locked-loop in the form of a single chip makes this very desirable circuit configuration practicable. The main expense is the cost of the chip, and this has gone down by 50% since the project started. It may well go down even further as the utility of this kind of circuit is appreciated by more engineers. Already other manufacturers are in the market.

2.6 How the touch-buttons are used

The nine positions on the screen where a button can appear are fixed in a 3 × 3 matrix and conventionally numbered from 1 to 9. (All planning has been done on the basis of a subsequent extension to 4 × 4, which fits in nicely with a 16-bit minicomputer word, but the pilot device described was made with nine buttons.) Programming of the buttons in PDP-11 BASIC, and subsequently in the SPS interpretive language NODAL is done with two subroutines. The first allows the programmer to draw a button as a rectangular box, and write in it a legend consisting of two rows of eight characters. For instance the statement

```
DO LEG(5,' BUTTON   FIVE  ')
```

causes the following image to appear in the middle of the screen:

```
+--------+
| BUTTON |
|  FIVE  |
+--------+
```

Touching this "button" with the finger now causes a bit to be set in the register connected to the button interface, and an interrupt to go to the computer. A control-language system variable (actually a function) called BUT changes value from zero to five when the button is touched.

Thus the control language statement

```
100 GO TO 100+BUT
```

will loop until button 5 is touched, and go to 105 when it is. (The touching of other buttons would give other non-zero values of BUT but this is protected against by software.)

The main use which is envisaged for the touch-buttons is the selection of accelerator subsystems and subsequently of control and monitoring programs. When a particular program has been entered, however, the touch-buttons are a resource of that program and can be made to control it or to exit from it.

An important second use which is planned is for selection from the hundreds of analog signals available in the control room and the assignment of selected ones to oscilloscope

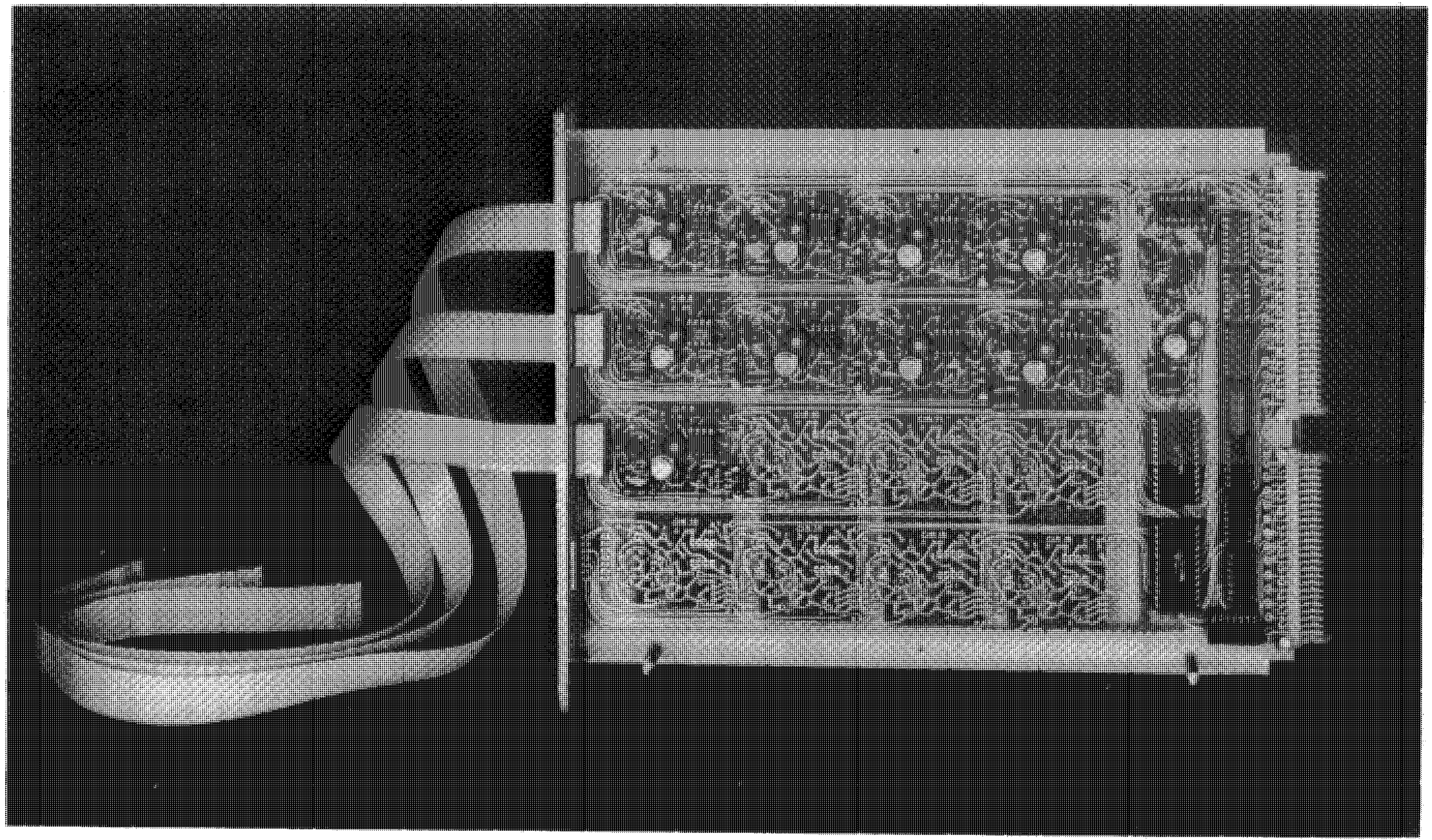


Fig. 5 Circuit board and connector cables for touch-screen (note that only nine of the sixteen buttons have been wired)

traces. In this mode a touch-button screen should replace a very large button panel without loss of convenience and flexibility.

It has been found that acknowledgement of action by means of an audible click gives the operator satisfaction out of all proportion to the amount of hardware involved.

2.7 Other possible devices

Touch-button screens seem to be a popular development (see list of references). Some of them are conceived of not as touch-buttons but as position encoders with a fairly high definition. However, given the limited requirement of about a dozen buttons, we think our method has the advantages of being purely electronic, having no moving parts or surfaces to corrode or wear out, and of leaving the display unit uncluttered and undedicated. The reliability is as good as that of conventional electronics. The circuitry is simple and therefore not expensive. For completeness the other principles which we know of are mentioned here, with references where available.

2.7.1 *The light-pen*

Light-pens work. It is, however, an acquired skill to use them, and they are primarily devices for interactive graphics, where precise pointing is vital. A light-pen would certainly not be acceptable as a substitute for an ordinary push-button.

2.7.2 *Ordinary button*

A mechanical button, made of transparent material, so that an area of CRT face is visible through it. The actuating mechanism, including the switch and its wiring, would have to be hidden behind the panel between the rows and columns of buttons. This method has merits but the presence of the mechanism precludes the use of the CRT for any other purpose.

2.7.3 *Optical method*[2)]

This is an arrangement involving the interruption of light-beams with the finger. The light-beams originate from lamps and are detected with photo-transistors. This device has been used for data collection on a beam-line. It is not cheap to do properly, and it suffers from the slight disadvantage of being a little bulky physically.

2.7.4 *Rayleigh waves*[3)]

A device using acoustic waves travelling in the surface of a sheet of glass. The incident wave is reflected by pressing on the glass, and the arrangement has been used for accelerator control on an experimental basis. The method requires quite a bulky frame around the screen, but it works.

2.7.5 *Hum pick-up*

An arrangement which picks up 50 Hz hum from a finger by direct contact, unless the operator is earthed. Using a field-effect transistor per button this method can be made to work. However, there may be problems in constructing a transparent panel with sensitive points and insensitive leads, and of keeping the sensitive points sensitive in spite of wear and dirt.

2.7.6 Cross-bar

A mesh of wires suspended above a mutually perpendicular set. The pressure of a finger brings one wire from each set into physical contact. The wires and supports can be made so thin and delicate that they are inconspicuous. The whole is protected by a plastic sheet. This method, although presumably having the unreliability of a home-built switch, has been used in Air Traffic Control and at the Stanford Linear Accelerator.

3. COMPUTER-CONTROLLED KNOB

3.1 Introductory remarks

The knob, which is assignable to any controllable variable of the accelerator from the interpretive control language, can also be used as a manual input of digital or analog information to the graphics system. As a computer input device, the knob is conventional, consisting of a Leine and Linde model 35A encoder, with 512 counts per revolution, interfaced with a CAMAC incremental encoder (SEN type 2IPE 2019).

The unconventional feature of the knob is that in addition to being a computer input device, it is also a computer output device. Instructions from the computer, via CAMAC, to the knob, may cause the knob to be, at will:

i) A knob with programmable resistance to turning, all the way from free movement to complete locking. This is useful both for giving the operator "feel" of the operations he is controlling, and also for limiting his actions, when necessary.

ii) A knob with spring-return to zero, with a small triangular pointer, apparently attached to the knob. This can be used for controlling the velocity of a variable, rather than its position.

iii) A multi-position switch, with detents and visual indication of the currently selected position. The number of positions per revolution has been set at 16 so that each index position of the switch shall cause the counter to increment by an exactly integral number (512/16 = 32), making the switch suitable for use in manually-controlled selection processes.

3.2 How the knob works

Figure 6 shows how the knob is arranged to be both an input and output device for the computer. Figure 7 shows the mechanical arrangement. The encoder is permanently attached to the operator knob through a gear train. Other devices are attached through gear trains containing electromagnetic clutches. The energizing of a clutch causes a particular device to be attached to the otherwise freely moving knob, thus restricting its movement in a suitable way. Figures 8a, 8b, 8c, and 8d show these phases diagrammatically.

The resistance to movement of the knob may be controlled by energizing an electromechanical brake with a current supplied from a digital-analog converter whose digital input is supplied from the computer. A digital value from 0 to 255 gives a proportional current, and this range of currents allows the knob to run freely at zero current and to be locked completely for maximum current. The brake used (Warner Model RF160) appears to introduce smooth proportional resistance at intermediate currents.

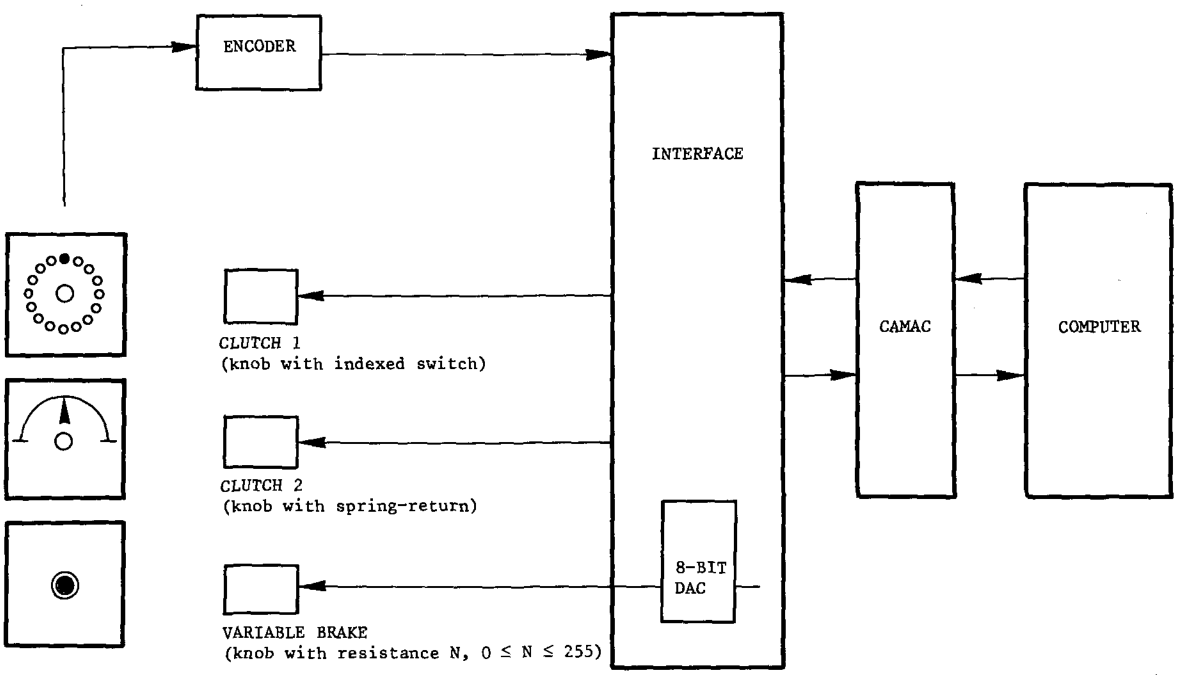


Fig. 6 Over-all connections of the computer-controlled knob

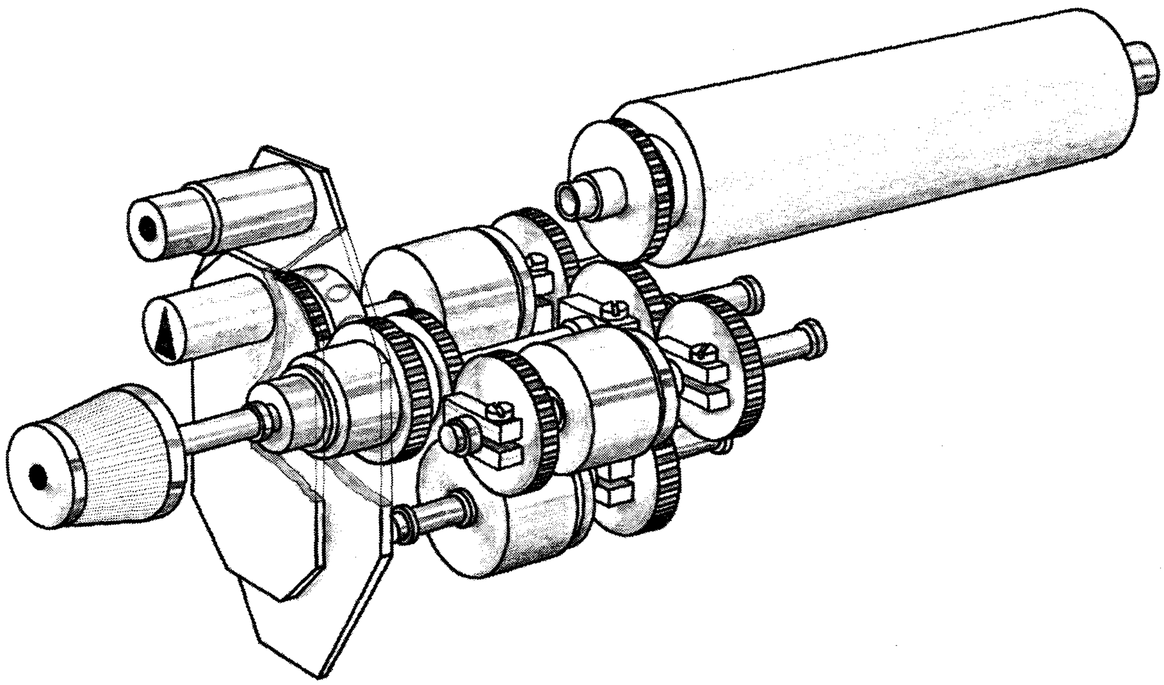
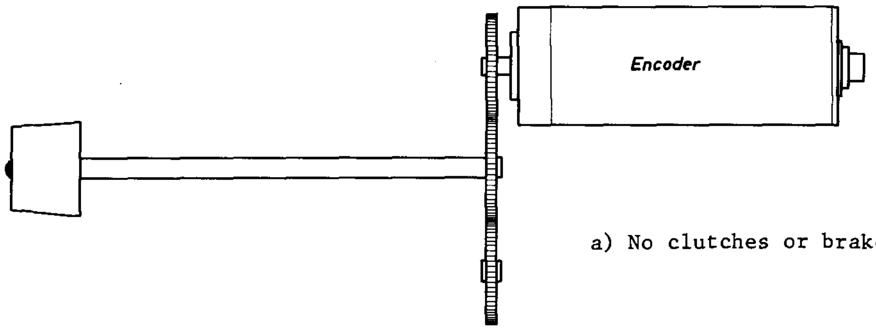
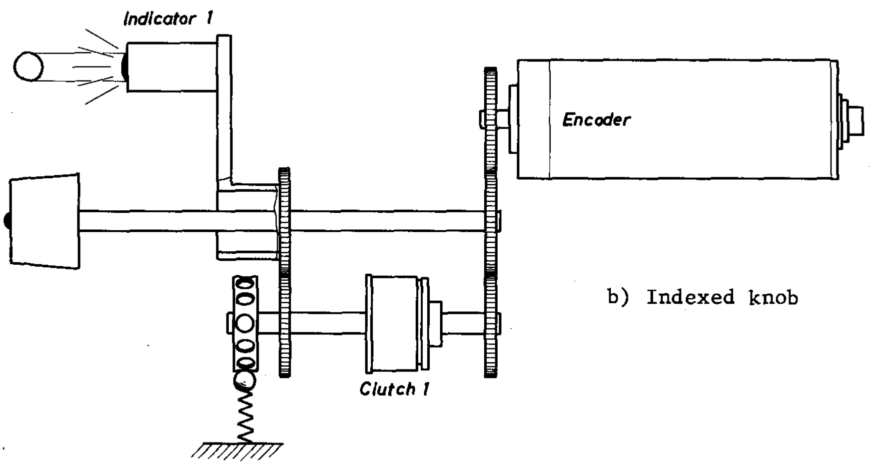


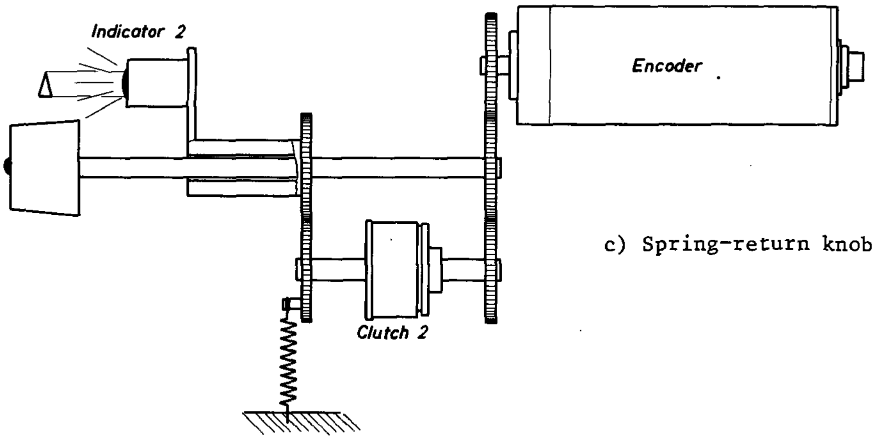
Fig. 7 Computer-controlled knob (housing and translucent front panel not shown)



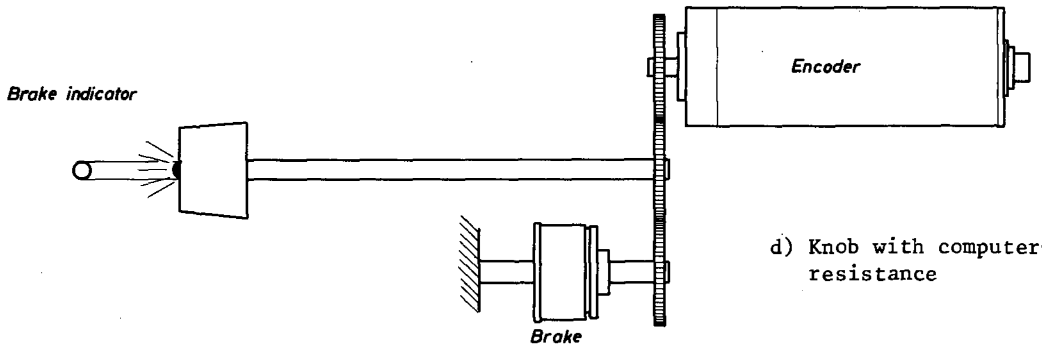
a) No clutches or brakes energised



b) Indexed knob



c) Spring-return knob



d) Knob with computer-controlled resistance

Fig. 8

The knob may be turned into a switch by energizing a clutch and thus attaching an indexer. The indexer consists of a spring-loaded ball running on a wheel with 16 detents.

The spring-return-to-zero motion is obtained by energizing yet another clutch, and attaching a device using a cam and two springs, to obtain the necessary progressive return force as the knob is moved away from the home position.

Visual indication of the behaviour of the knob is obtained by lamps. One of these is in the centre of the knob, and shows when controlled "feel" is available. The others shine through the translucent front panel and are only visible when energized. They are on arms mounted concentrically with the knob and are driven by gear trains through the appropriate clutches so that each only moves and shines when it is needed. The gearing is such that the indicator appears to be rigidly attached to the knob.

The entire device is encased in a cylindrical body 287 mm long and 146 mm in diameter. Three knobs will just fit side by side in a 19″ rack.

3.3 How to use the knob

The knob will finally be used on a Norsk Data NORD 10 computer using NODAL, a specially written control language. However, the following description of the statements currently enabling the knob to be used under PDP-11 BASIC will show the following principle:

- the statement LET CAM (crate, unit, 0, 16) = K puts an initial value K into the knob increment register;
- the statement LET X = KNB(1) reads the current value of the knob increment register into X;
- the statement LET KNB(n) = N sets the mode of the knob:

  n = 1 gives an indexed switch
  n = 2 gives a spring-return knob
  n = 3 gives a knob with resistance N ($0 \leq N \leq 255$).

3.4 Future developments

The knob is currently interfaced to CAMAC and works. An improved model is being built which will have better "feel" characteristics.

There is space in the gear train for additional clutches and other devices: The attachment of a small d.c. motor could be envisaged which would be used, for example, to give a "flywheel" action to the knob. There is no need for explicit angle control of this motor, since there is an encoder and a computer in the control loop.

Acknowledgements

Many people helped with this project; amongst them the following contributed significantly: Mr. A. Merlino, who did the mechanical design of the knob; Mr. C. Nichols (NP Division); Mr. M. Flamier (West Workshop) and Mr. A. Gandi (Surface Treatment shop) who worked on the touch panel; and Mr. P. Farley who did the computer programming for both devices.

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2) E.M. Mott, A transparent touch-screen device for interactive computer-graphics displays, RHEL/R 248, February 1972.

3) D. Fryberger and R. Johnson, IEEE Trans. Nuclear Sci. NS 18 No. 3 (1971).