

12 Sunnysfield
Mill Hill
London NW7 4 RG

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Mr Andrew Tristoffy
Digital Computer Museum
One Iron Way
Marlboro 01752
Mass.

2-17

Dear Mr Tristoffy,

Since my letter of December 4 last I have pursued numerous inquiries regarding the Colossus bedsteads but with, I regret to say, very little result. I think that you will realise that people asked to search their records of long ago do not in general reply very quickly especially if they have to report that they can find nothing. For that reason it is still possible that something may turn up but I think that we must now accept that that is unlikely and I am therefore sending you such information as I have been able to obtain.

You may be interested to know that I traced the draughtsman who designed the bedstead in the hope that he might have some record in a notebook or his memory. In fact he could not even recollect having done the work: which is perhaps not so surprising considering that he is now 77, it was 39 years ago and he was not told at the time of the purpose of the construction which might have fixed it in his mind.

The optical system of the tape reader was described in a paper by A C Lynch of which a copy is enclosed. The only practical detail now known is the photographic mask shown in one of the lecture slides.

The frames of the bedsteads were 7ft6in high, 4ft long and probably 2ft6in to 3ft wide. The first two dimensions can be obtained from the photograph but not the third. The frames were fabricated out of $1\frac{1}{2}$ by $1\frac{1}{2}$ inches angle iron joined at the corners by rivetted gussets. Two such frames were bolted together to make one structure 8ft long. The arrangement of the pulleys on the frames can be seen in one of the photographs (lecture slide) and is shown schematically in the enclosed sketch (by someone who maintained the machines) indicating the path of a maximum length tape. Each tape was looped around as many pulleys as its length required with the final adjustment made by a pulley on a spring-loaded arm which could slide up and down an inclined member of the frame which can be seen in one of the photographs. The spring-loading was intended and designed to maintain enough tension in the tape to keep it on the pulleys without breaking.

The pulleys were of aluminum alloy, the free-running ones being, it is believed 3 inches in diameter and the driving motor pulley 4 inches diameter. Toby Harper has one of the free-running type but without bearings or spindle. The only authentic Colossus drawing that has been found is that

enclosed of pulleys X and Y made for special machines. These are three-tape pulleys, the regular machines having only one tape, but the drawings show the profile and allow some of the dimensions of the single tape pulleys to be inferred together with some idea of the spindle and ball-bearing mounting of the pulleys.

Some more detailed information might be obtained from the photographs, in which I would be willing to assist but which I will not attempt unless and until I hear from you that it would be useful to undertake.

Yours sincerely,

A handwritten signature in cursive script that reads "Tommy Flowers". The signature is written in dark ink and is positioned above the typed name.

T H Flowers

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THE SECRET DIGITAL COMPUTERS OF 1943

A. C. Lynch

1 INTRODUCTION

In 1976 Randell compiled a paper¹ which showed that electronic digital computers had been built in 1943 and 1944 by the British Post Office for use at Bletchley Park. In February 1977, a BBC Television programme in the "Secret War" series disclosed that these computers had been used for decoding intercepted radio messages. Section 2 of this paper is based on these two sources; Section 3 adds some new detail.

There is almost no evidence about these computers except personal memories. Six photographs in the Public Record Office² show their size and general arrangement, without much detail, but the sending of the photographs to the P.R.O. implies that the machines themselves no longer exist. Drawings of the machines were formerly held in Post Office files but they are not there now. (The index at the Post Office Research Centre lists 43 drawings, some of many sheets each, whose titles were, or were altered to, "Apparatus, Telegraph Transmitting", a cover-name used for the computers. They are dated from June 1943 to February 1945. All are marked "Transferred to F.O.") Some of these drawings were circuit diagrams, but probably incomplete, for the circuit diagrams are said to have been drawn only in manuscript. The design of the complete machine was disclosed only to those few engineers necessary to the assembly and maintenance of the operational units. One glass plate used for experiments with the optical tape-reader has survived.

The machines were needed to process digital data according to programmes devised by mathematicians; to be useful the work had to be completed within a few hours, a requirement which could be met only by a speed of processing far beyond any that had been used before.

2 GENERAL DESCRIPTION OF THE MACHINES

Input data to the machines came from standard 5-hole teleprinter tape, each position on the tape storing 5 bits. Data from two sources were used, one source being an encoded message and the other a machine of the kind which had been used to encode the message. To satisfy the processing-time requirement, the input data had to be available at at least 2000 5-bit groups per second. The corresponding processing speed was of the order of megabits per second, but by parallel processing and other devices it was reducible to the order of 10^2 bits per second.

Mechanical devices available in 1943 could not reach these speeds of tape reading or processing. Thermionic valves offered speed, but their possibilities as logical switches had been little explored. Moreover, valves were believed to be so unreliable that no apparatus using them in large numbers could be capable of continuous operation. So for the first machine, known to its users as the "Heath Robinson", valves were used sparingly, with electromagnetic relays and other telephone-type switches for the slower operations. This machine, much of which was designed by C.E. Wynn-Williams, was valuable for validating the programmes which had been devised, but it was too slow for operational use. T.H. Flowers made higher speeds possible by using valves freely; he took the

A.C. Lynch, now of University College, London, was formerly with the Post Office Research Station.

view (which proved correct) that valves were reliable if they were kept running continuously, never switched off. The first of his machines, known as "Colossus", used 1500 valves; subsequent models used up to 2400 valves each.

Conventional electro-mechanical reading of holes in paper tapes at 2000 characters per second was impossible. Photo-electric scanning was suggested by F.O. Morrell and used successfully. But the tapes tore easily when they were driven by means of their sprocket-holes (the normal method for telegraphy at low speeds). A friction drive was used instead, and the sprocket holes were detected optically to provide a timing signal - a further complication, in 1943 terms, needing yet more valves. There were 11 detectors for each tape, all operating simultaneously; one for the sprocket holes, and 10 for the code holes in two successive positions on the tape.

For the Heath Robinson, an optical tape-reader was constructed in a few weeks, using whatever components could be obtained quickly. There were mistakes due to inexperience with closely-packed arrays of valves, but the equipment seems to have operated well enough to justify further development, and in December 1943 the prototype of a well-engineered tape-reader was brought into service as part of the first Colossus. Colossus had only one tape; the other had been replaced by (using the modern name) a shift-register store using hundreds of valves. It proved successful, and machines with further improvements were quickly built.

Although these machines were designed for a special purpose, they included all the essential features of a general-purpose digital computer, including:

large semi-permanent data store (namely, the punched paper tapes read cyclically);

digit and word registers (the temporary stores based on thermionic valves); arithmetic unit for logical processing including binary arithmetic, Boolean operations, and counting;

variable programming including conditional instructions.

There was no large random-access store, for in 1943 there were no ferrite cores and no magnetic tape, and other methods of storage would have been cumbersome. Variable programming required the manual operation of plugs and cords of which a very large number were provided.

3 THE HIGH-SPEED TAPE READER

This section of the paper describes the high-speed tape reader developed by E.A. Speight and the present author (who knew nothing about the rest of the machine until 1976). The specification was that it should provide an output of +1V for a hole, zero for no hole, the signal being as nearly as possible a square wave lasting for 1 ms when the tape was driven at 1000 characters per sec.

Three types of photo-cell existed in 1943: photo-conductive, photo-voltaic, and photo-emissive. The first was very slow in response and the second liable to fatigue, so the third was chosen: It too is liable to fatigue, but this was not known when the choice was made. Heath Robinson used standard gas-filled cells. But it was not certain that enough of them could be obtained for the Colossus programme; and, further, their response decreases at frequencies above 10 kHz, so that as a rectangular wave-form was wanted at 1 kHz and more, a change to vacuum cells was desirable. No ordinary cell was suitable, but fortunately a large supply of vacuum cells was available from some unidentified work which had been abandoned. They had conical cathodes, and the connections were brought out only as wire ends, but they were otherwise suitable, and 1200 of them were fitted into octal valve-bases in a laboratory at Dollis Hill. (The P.R.O. photograph identifies them as "RCA" cells. But they appear to be of the general type for which seven patents were ~~issued~~^{issued} to Baird Television and Cinema-Television between 1940 and 1944.)

Both gas-filled and vacuum cells were of about 21 mm diameter and as the holes in the tape were spaced at 2.5 mm some optical magnification was needed.

The tapes were illuminated by a 10V 75 W lamp (as used for sound films) with a condenser lens, and a photographic lens of 50 mm focus formed a magnified image of the tapes on a glass mask behind which the photo-cells were mounted. The optical system for Colossus is shown in Figure 2; that for Heath Robinson differed in the omission of the final condenser lens for each photo-cell and in the use of 22 cells for the two tapes instead of 11 for one. In the Heath Robinson each photo-cell was directly coupled to the grid of a cathode-follower output valve; in Colossus there may have been two valves per photo-cell, and the sprocket-hole detector was a.c.-coupled.

The magnified images of the tapes moved over masks (made photographically on glass plates) which were shaped as double crescents (see Figure 1) in an attempt to obtain a nearly constant output as a circular spot traversed them. The valve circuits therefore received a fairly good rectangular signal which needed little further limiting to provide the specified output.

4 SUBSEQUENT USE OF THE TECHNIQUES

Flowers's team, after the war, built an early digital computer ("Mosaic") and also applied the techniques to the design of electronic telephone exchanges. The tape-reader had no direct descendants. Paper tape can be read slowly, but it tears too easily to be acceptable for high-speed work except in the special case of the same input being required over and over again from a closed loop. The development of high-speed stores has made the tape-loop system obsolete.

ACKNOWLEDGEMENTS

Most of the information in Section 2 of this paper is taken from Ref.1. I am indebted to Dr. T.H. Flowers for helpful criticism of my first draft.

REFERENCES

- 1 B. Randell, "The Colossus": a paper presented at the International Research Conference on the History of Computing, Los Alamos, June 1976
- 2 Public Record Office, reference FO 850/234

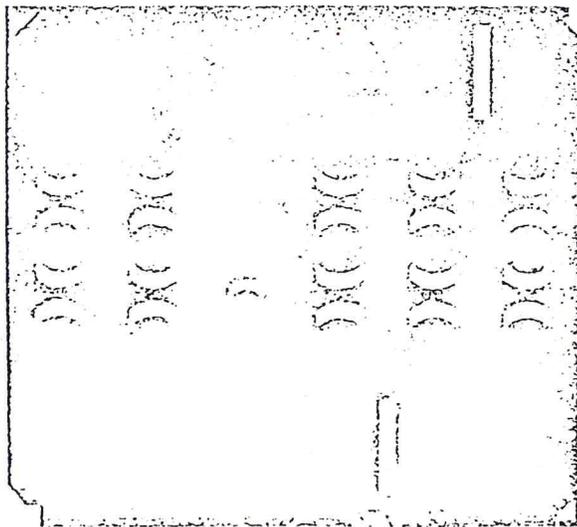


Figure 1: the mask-plate for Colossus (photograph from a plate used for experimental work and thus not sent to Bletchley Park). Approximately half-size. The rectangles are to help in alignment of the mask in the apparatus.

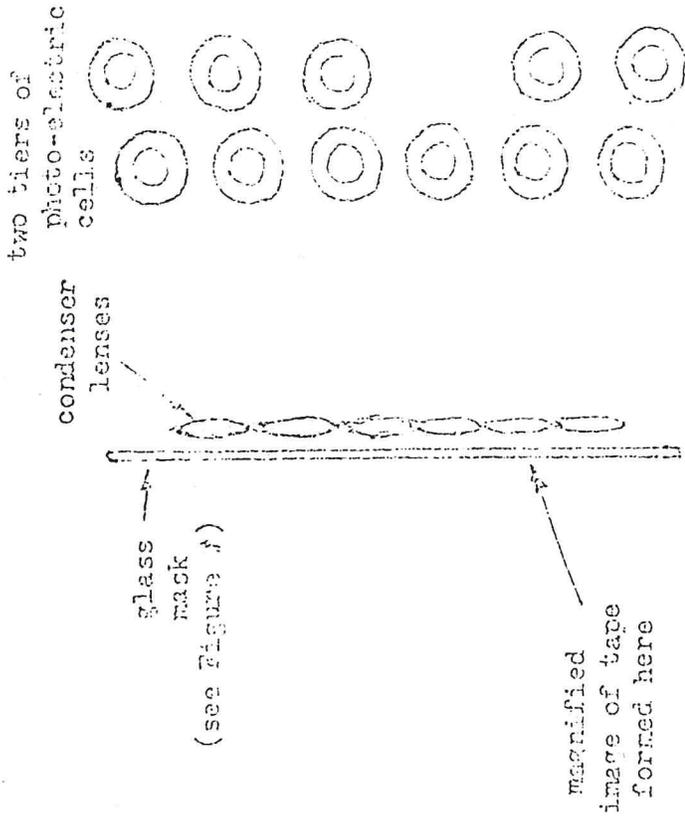


Figure 2: optical system for Colossus, drawn from memory. Not to scale. Distance from tape to mask, 24 in. approximately; spacing of photo-cells, approximately $1\frac{2}{16}$ in. between centres.

