The Control of Thermionic Valve Envelope Quality by Thermal Shock Testing

By G. D. Redston*

The factors controlling the failures of all-glass valves in thermal shock tests are discussed. It is pointed out that the different thermal shock tests bring out different defects.

Evidence is given showing that the downward thermal shock test results are more nearly correlated with service life than those of the upward thermal shock test. Tempering the valve base improves resistance to downward thermal shock, but has failed to produce a significant change in the number of failures on life test.

IN a previous paper[1], the writer has described the glass working processes in the manufacture of the all-glass thermionic valve. While glass has many virtues as an envelope material for valves it has the disadvantage of being mechanically weak, and the valve manufacturing processes can leave the glass envelope in a strained state so that it cracks spontaneously after some time in service. By careful factory control cracking in service is minimized, but the

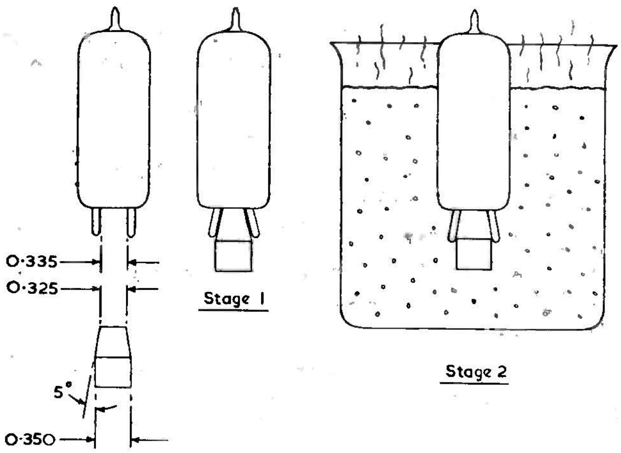

Fig. 1. The 'B' test

responsibilities of some modern valves are such that this matter cannot be left to chance. Tests for proneness to spontaneous failures must be applied before batches of valves are dispatched.

The usual procedure is to apply a thermal shock test on a representative sample group of valves, accepting or rejecting the batch according to an acceptance quality level with the help of statistical tables[2].

Thermal shock tests consist either of sudden heating or sudden cooling and are called respectively upward or downward thermal shock tests. The most widely used test for valves is the 'B' test which is a form of upward thermal shock test.

In this article the function of such thermal shock testing is examined with the following questions in mind:

(a) Do thermal shock tests adequately measure the "spontaneous failure proneness" of a group of valves ?

If so;

(b) Which form of thermal shock test gives the most helpful indications ?

To do this, the well known 'B' test is examined. It is pointed out that the types of failure which occur on B test do not necessarily occur in service; a better test is the downward thermal shock test.

The Upward Thermal Shock Test

The specification for the B test[3] states "The test shall consist of forcing the pins of the valve over the specified cone (Fig. 1) and then completely submerging the valve and cone in boiling water for a specified time . . . the water container shall be at a temperature between 97°C and 100° . . . the water container shall have a minimum capacity of 2 litres per 15 valves and shall be at least three-quarters full . . . valves before test shall be at room temperature and shall have been submitted to approved pin-straightening.

(a) Align the axis of the valve with the axis of the specified deflexion cone and carefully push the small end of the cone into the circle formed by the valve pins until the cone lies firmly against the valve bottom.

NOTE. If some pins are bent more than others the test is being made improperly.

(b) Place the holder of valves into boiling water so that the valves and cones are completely submerged for a period of 10 seconds.

(c) Remove the valves from the water and allow to cool to room temperature on a wooden support."

The defects which the B test detects are, in common with all upward thermal shock tests, those on the inside surface of the envelope. In addition, the test detects many of the defects associated with the contact pins.

For convenience in fault diagnosis a classification of types of crack was built up on the observation that the majority of base failures occurred in one of four ways:

Type 1. Crack tangentially at the seal.

Type 2. Crack radially across the base through a pin.

Type 3. Crack radially across the base *not* through a pin.

Type 4. Crack tangentially at the pin circle, through a pin.

This classification was used in the experimental work described.

Those defects which were observed to cause B test failures in the factory practice were:

(a) Crizzles and laps on the inside surface of the base.

(b) Under-melted seal.

(c) Over-melted seal.

(d) Pin circle diameter errors.

(e) Pins too stiff.

(f) Incorrect tempering.

(g) Mismatched bulb and base glass.

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(a) *Crizzles and Laps on the Inside Surface of the Base*

Cracks, crizzles and laps on the inside surface of the base acted as fracture origins for cracks which were usually of Type 3.

(b) *Under-melted Seal*

If there were internal crevices between base and bulb after sealing there was a tendency to Type 1 failures on B test.

(c) *Over-melted Seal*

When the seal was over-melted the bulb adhered to the stem fillets, forming a crevice as well as thickening the glass in the region of the seal. Both of these factors led to Type 1 failures on B test, although Type 2 and Type 3 cracks sometimes occurred in this case.

(d) *Pin Circle Diameter Errors*

If the pin circle diameter was too small the B test plug

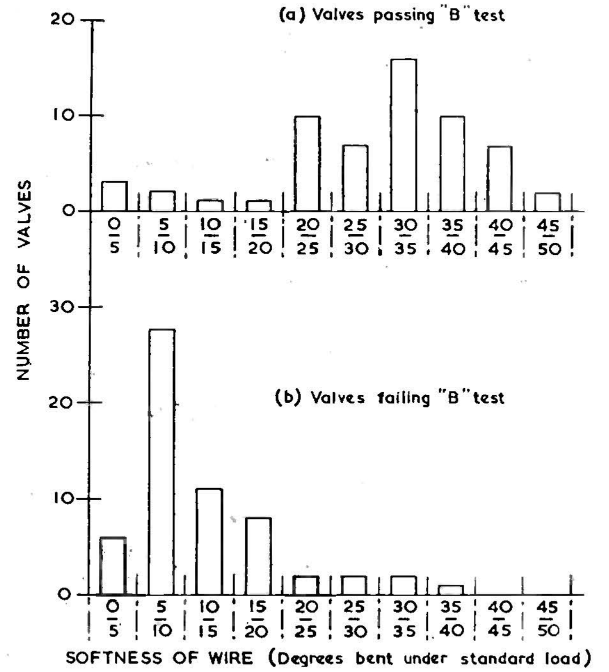


Fig. 2. Effect of softness of wire on 'B' test failure rate

would tend to break the base by forcing the pins apart. In a particular case, where 700 valves with p.c.d. 0·005in below standard were tested, 15 failed on B test with typical Type 4 cracks. When 102 valves with p.c.d. correct at 0·375in were made up similarly and tested there were no failures from this cause.

(e) *Pins Too Stiff*

Even with correct p.c.d. the insertion of the B test plug forces the pins out somewhat so that pin stiffness plays a part in the strain transmitted to the base.

Taking some envelopes which had passed and some which had failed the B test, their pins were carefully extracted and the stiffness measured. For this purpose a "Bendometer" constructed to ASTM Specification B113-41 was used. The results (Fig. 2) showed that the proportion of hard pins in valves which had failed was very high. The failures in this case were also of Type 4.

(f) *Incorrect Tempering*

Tempering is one of the less understood factors affecting the B test results.

Laboratory tests established a broad relationship between 'radial stress' (observed by looking through the base) and failure rate (see Table 1).

TABLE 1

Relationship of Apparent Stress and B Test Failure

APPARENT STRESS (mμ)	FAIL B TEST (per cent)
68–91 T	60
23–45 T	43
Nil	0
0–23 C	0
23–45 C	0
45–68 C	50
68–91 C	66

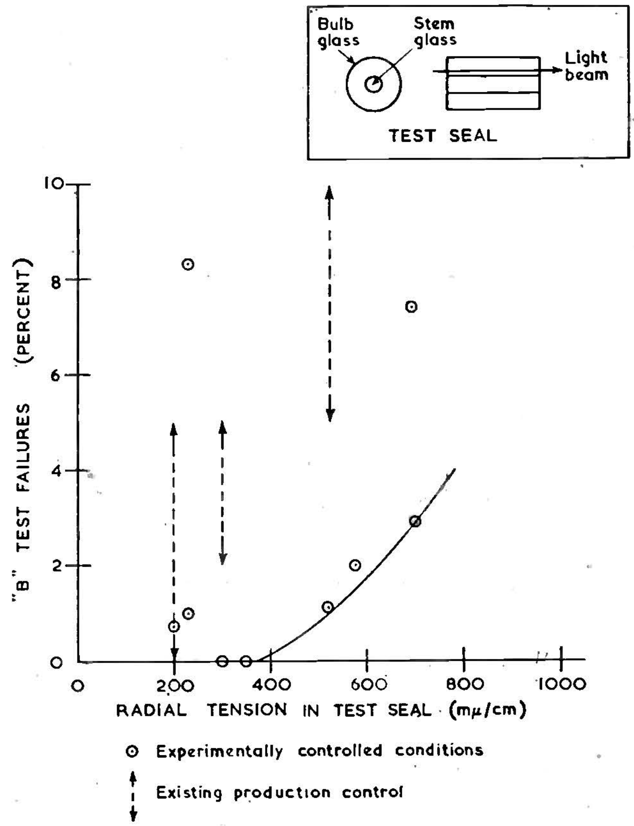


Fig. 3. Dependence of minimum failures 'B' test on degrees of mismatch

This indicated that tempering should aim for the 'low compression' condition.

More will be said later on tempering.

(g) *Mismatched Bulb and Stem Glass*

The effect of bulb-stem expansion mismatch was found to be a most important factor in controlling B test failures. Valves were made with a number of pairs of glasses using the best available glassworking technique and were then B tested. The mismatch of each sealing pair was measured in a standard manner using the stress in an annealed bead seal of bulb glass on stem glass cut for axial sighting[4]. The results were as shown in Fig. 3 and Table 2.

The cracks were in general of Types 3 and 2.

As is seen from the table some of the better pairs were also tried in production where manufacturing errors apparently caused increased B test losses.

From this work (which summarizes observations taken over many months) it was concluded that as the mismatch increased and the stem became increasingly under tension the difficulty of setting the sealing-in machine increased. Beyond a mismatch represented by 500mμ/cm in a standard seal no sealing technique which gave low B test results was discovered.

TABLE 2
Effect of Mismatch on B Test Results

STRESS IN SEAL (mμ/cm.)	FAIL B TEST (per cent)	
	EXPERIMENTAL	PRODUCTION
200 T	0·7	0 to 5
230 T	8·4 & 1·0	—
300 T	0	2 to 5
350 T	0	—
520 T	1·1	5 to 10
580 T	2·0	2
700 T	2·9	—
700 T	7·5	—

Failures in Service Compared with B Test Failures

Having now outlined those factors which were found to affect the B test, attention was directed to the types of valve failure which occurred in service. In general, glass failures did not figure largely in service returns on valves, but those valves which did come back from the field for this reason were examined and classified. Of the valves which failed for cracked base, the cracks were classified into the four types and it was found that Type 2 largely predominated. This was not at all the case with B test failures! Fig. 4 shows the comparison. Further analysis showed that many of the defects which the B test singled out in the valves did not ever cause field failures. Consideration of the individual defects verified this.

(a) *Crizzles and Laps on the Inside Surface of the Base*

In fact approximately 20 per cent of cracked bases did fail from internal crizzles in the base. For this defect therefore the B test was of value.

(b) *Under-melted Seals*

Origins from under-melted seals did not occur in practice.

(c) *Over-melted Seals*

Over-melted seals did not fail in service, although they looked very poor.

(d) *Pin Circle Errors*

There was insufficient evidence to deduce whether valves had failed from pin circle errors. Such errors are influenced by socket design, as failures can be caused by inaccurate dimensioning and also by inadequate float of the contact clips in the socket[5]. If the socket clips were absolutely rigidly fixed then the base would tend to split (probably Type 2 cracks), but the forces needed to split the base would be relatively large. Normal valves fail at over 9lb radial force per pin on a test of a few seconds' duration; allowing a factor of three for the strength-time effects the socket must therefore exert a steady lateral force of at least 3lb to produce failures in service. Most modern sockets are designed with adequate freedom of movement for the contact clips. Furthermore, limits of the order of a few pounds weight have been set for the insertion and withdrawal forces of a gauge with standard pin dispositions[6]. These indirectly limit the lateral force that the socket can exert on the pin.

Thus only a bad displacement of the valve pin from its true geometrical position is likely to cause failures in modern sockets. On the other hand, the B test produced copious failures when the p.c.d. was too small. For other errors of the p.c.d. the B test was completely insensitive.

(e) *Pins Too Stiff*

Imperfections of pin circle and socket design and also bad handling were more likely to crack a valve with stiff rather than soft pins. It was frequently found that an envelope returned for cracked base showed vestiges of severe bending of the originating contact pins caused probably by careless extraction from the valve socket. Stiffness of pins in itself was not a disadvantage in valve service. The B test, however, always tended to produce failures with stiff pins.

(f) *Incorrect Tempering*

Experiments have indicated that there is no variation of service failures within a wide range of degrees of tempering. B test results were markedly affected by degree of tempering.

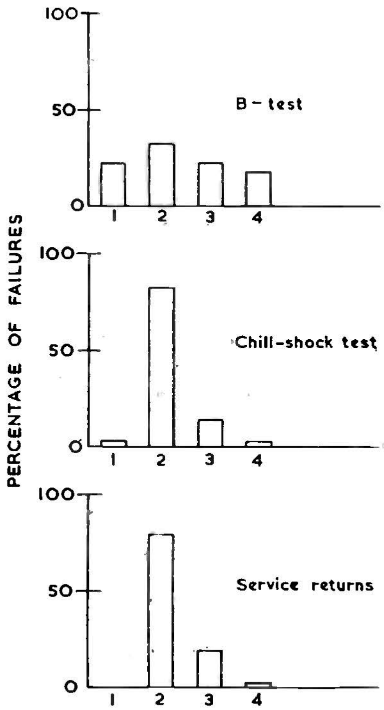


Fig. 4. Fracture type-distribution for 'B' test chill-shock test and service returns

(g) *Mismatched Bulb and Stem Glass*

No serious study of the effect of mismatch on service failure had so far been made.

On this analysis it was clear that although the B test was useful for controlling a number of possible manufacturing errors in the factory a test must be sought which would give a more realistic indication of the service life of a batch of valves.

The Downward Thermal Shock Test

The chill-shock test, i.e. a test in which the valve is suddenly cooled from some higher temperature, has the advantage of being more in line with modern ideas of glassware testing. In contrast to the upward thermal shock which probes the inside surface of the glass envelope, the chill-shock test puts the outside surface of the glass into sudden tension and any weak spots are thus made to break. It is the outside surface of the glass article which suffers impact, atmospheric corrosion and stresses from any mechanical loads such as clips etc., and it is the outside surface which is therefore really interesting.

EARLY CHILL-SHOCK TRIALS

The original chill-shock tests carried out by the writer were made at a time when it was necessary to detect fierce strain rings in valve envelopes. After some preliminary tests it was found that strain rings could be identified by a chill-shock from an air oven at 175°C to water at 20°C:

Good envelopes:	22 tested,	3 failed.
Strained envelopes:	44 tested,	19 failed.

Further work showed that the test sensitivity was poor, in that slightly strained envelopes were not detected, so this work was discontinued.

Serious interest was directed to the chill-shock test when it was found that the type of cracked base obtained corresponded with the type of crack obtained in service failures. (See Fig. 4). As a result of this observation it was decided to investigate the chill-shock test thoroughly, with the object of using it side by side with the B test as a quality control.

Chill-shock Tests with B Test Plug

Tests were carried out by first inserting the B test plug then slowly heating the valve in water and finally giving it the chill-shock. Increasing temperature differences were used for the shock; the " hot " bath was water and the cold was either water or, for 0°C, salt water and ice[7].

A large group of valves was tested to establish the statistical variation to be expected. Groups of 20 valves were selected at random from a bulk sample of several hundred valves and were subjected one at a time to the chill-shock routine, care being taken to keep the motion and time of transfer the same for all valves. The results are shown in Fig. 5. For the particular batch of valves tested the temperature for 50 per cent failures was 84°C. The cumulative failures curve fitted the Normal (Gaussian) distribution, giving a coefficient of variation of 22 per cent. (But the present data could be fitted almost equally well to a straight line. The straight line has no obvious physical significance however.)

Using the same batch of valves, experiments were made utilizing an oil bath for heating. In this way chill-shock temperatures of 110°C and 120°C were reached, but the failure curve then gave a higher 50 per cent failure value. It was thought that the thin layer of oil carried over with the valves impaired the heat transfer efficiency of the cold water. A detergent was added to the water in an attempt to remove the suspected oil film, but no significant improvement resulted.

Chill-shock Tests Without B Test Plug

With further valves from the same batch chill-shock tests were carried out using hot water for shocks up to 90°C and an air oven for the remaining shocks up to 180°C.

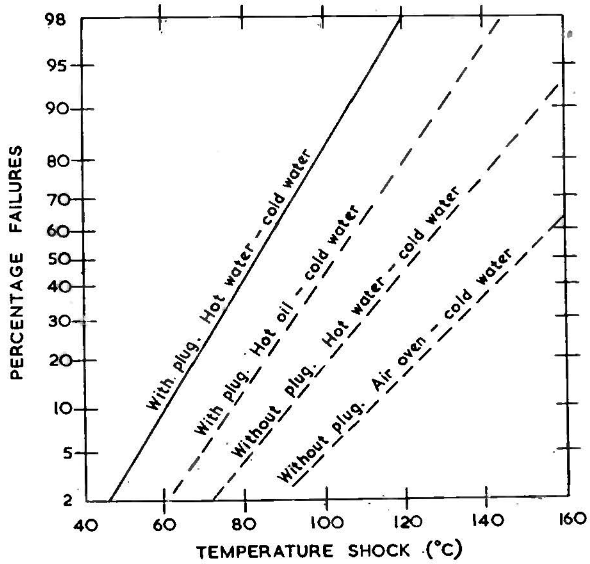


Fig. 6. Relationship between results of various types of chill-shock test on miniature valves sampled from a uniform batch

The results for the various forms of chill-shock tests are shown in Fig. 6. It was found that the use of the plug increased the failure rate and that there was a greater breakage in water to water tests than in the other forms of test.

The defects which might be expected to cause failures on chill-shock tests are:

(a) Crizzles on the outside surface of the base.

(b) Absence of gas cushion where the contact pin enters the glass.

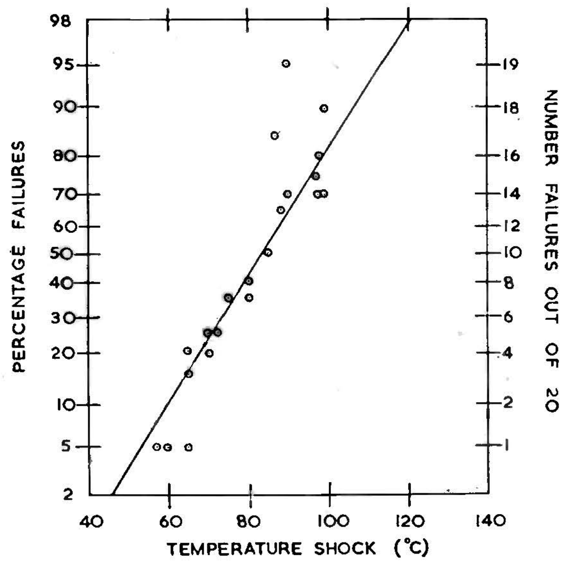
(c) Mismatched bulb and base glass, and

(d) Incorrect tempering.

Crizzles and gas-cushion defects are, in effect, small cracks which extend on chill-shock test and probably in service. In manufacturing practice, therefore, care was taken to avoid them. The effect of varying mismatch between bulb and base glass on chill-shock test was not studied because those glasses selected for B test suitability also proved satisfactory for chill-shock and in service. As chill-shock testing gave conflicting results, a closer study of tempering and its effects was necessary.

Fig. 5. Probability plot of effect of temperature shock on proportion of failures on a chill-shock test which used the 'B' test plug

Note: Each point represents the failure rate in a batch of 20 valves tested once only.



Analysis of Layer Stress

Tempering sets up a sharp stress gradient in the base of the valve. In the first place a more detailed experimental analysis of this 'layer' stress was required. Photoelastic measurements on normal valves using suitable immersion liquid (bromoform) established that the apparent layer stress passed from quite strong tension on the inner surface to a compression on the outer surface of a similar order (Fig. 7(b)). By varying the tempering the stresses were increased (Fig. 7(c)) and by annealing they were almost eliminated (Fig. 7(d)).

The curves were made more complicated, however, by the presence of depressions in the centre of the button stem. Special stems with no depressions were therefore prepared. These gave clearer layer stress curves, the shapes of which could be due to:

(a) Tempering effects.

(b) Differing amounts of highly stressed bulb glass through which the light beam has to pass, and

(c) Slight bending action by the bulb on the base.

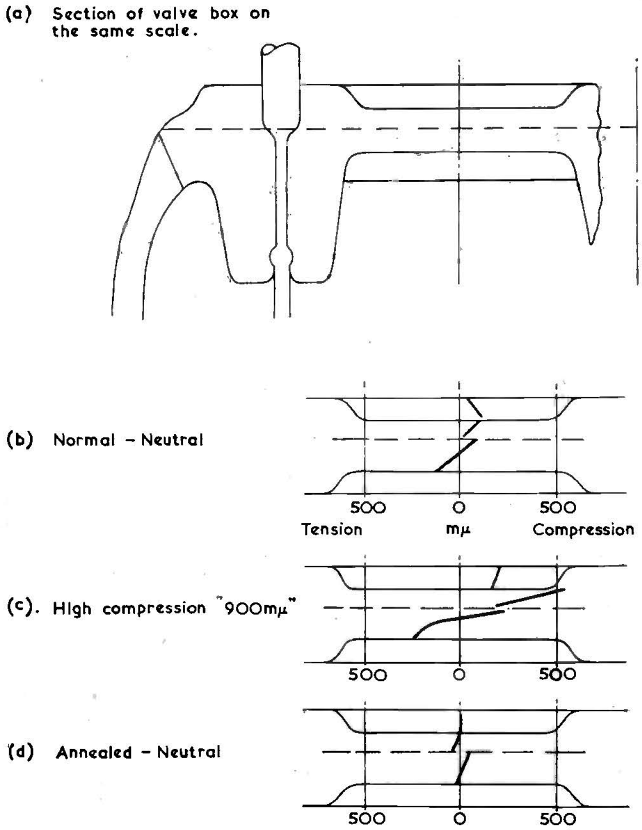
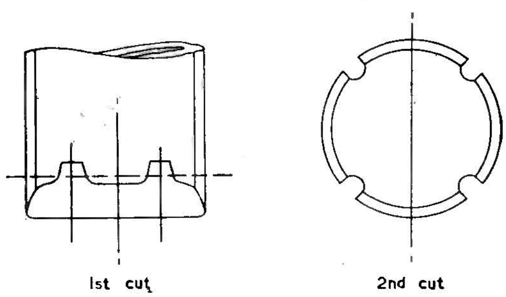


Fig. 7. Retardation gradients resulting from various strain-setting arrangements

Fig. 8. Stages in cutting away bulb glass to determine the effect on layer stress



The relative importance of these three factors was investigated by examining the stress pattern after deliberately removing a source of stress by cutting the glass bulb away from the stem. In the first cutting (Fig. 8) the bulb glass was sliced off at the level of the top of the stem. Although this reduced bending of the stem, it left a ring of stressed bulb-glass around the stem. In the second cutting, this ring of bulb-glass was slotted radially to break its continuity and to reduce substantially any circumferential stress present in the bulb. Those two cuts successively reduced the apparent internal tension layer. The external compression layer was almost unchanged (Fig. 9).

Although annealing reduced the retardations considerably (Fig. 7(d)), a detail which still remained was the step in the stress gradient at the extremity of the bulb seal. The slight step was consistent with the bulb being in either circumferential compression or in radial tension.

From these observations it was concluded that the apparent layer stress distribution due to tempering itself was of the same form as in any other force-cooled article and that the bulb stresses had a considerable influence only on the internal apparent stress, although in practice the internal centre depression in the stem masked off the region in which this influence was greatest.

For routine investigations of layer stress it was decided to choose the centres of the top and bottom depressions for the sighting points.

Effects of Layer Stress on Chill-shock Results

A series of experiments was carried out[7] to determine the influence of the layer stress on chill-shock results. Ten groups with twenty dummy valves in each group were sealed-in, each group with a different sealing technique. For each group, average values (Table 3) were found for the layer stress at the two sighting points.

TABLE 3
Effect of Layer Stress on Thermal Endurance (Average of 6 out of 20)

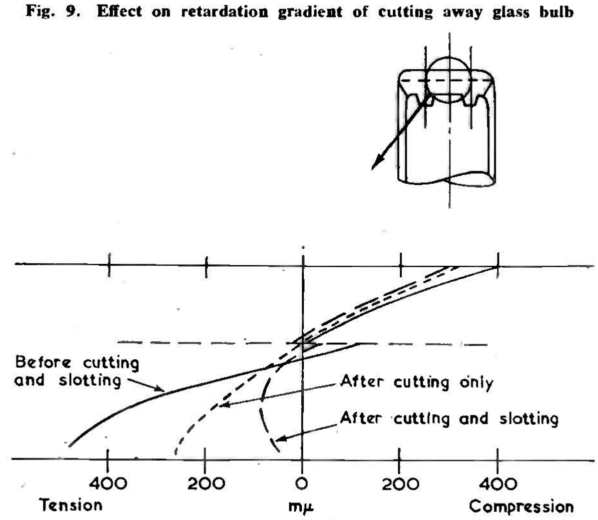
EXTERNAL (C) (mμ)	INTERNAL (T) (mμ)	T + C (mμ)	50 PER CENT FAILURE TEMPERATURE (°C)
630	270	900	64
290	318	608	85
210	420	630	90
176	273	449	93
198	220	418	84
104	170	274	95
162	30	192	64
96	101	197	47·5

Each group was chill-shock tested to find the 50 per cent failure temperature at temperature intervals increasing by 10°C until all failed. It was found that correlation between the individual external or internal layer stress reading and the 50 per cent failure temperature was poor. However, on the theory that the *sum* of the two represented the slope of the layer stress gradient and hence the degree of tempering, an interesting correlation was obtained (Fig. 10).

This was later confirmed by production experience, Fig. 11 showing the form of correlation obtained. It appears that the tempering at first rapidly increases the strength, but that further tempering leads to a decline.

From the results shown in Table 4 it was seen that over the range of layer stresses studied there were no failures on life. For practical purposes then layer stresses had little or no effect on life, although they did affect the chill-shock test results.

Fig. 9. Effect on retardation gradient of cutting away glass bulb



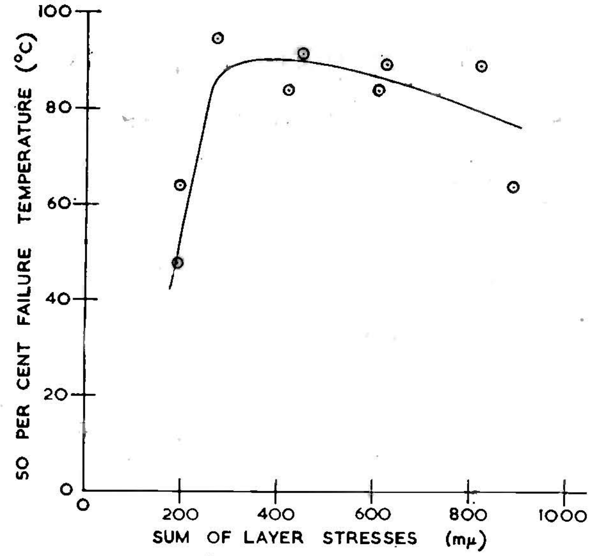


Fig. 10. Effect of layer stress on thermal endurance of miniature valves

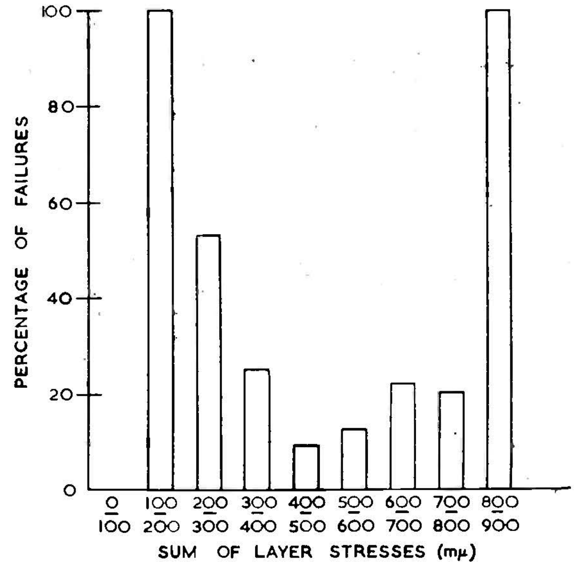


Fig. 11. Relationship between layer stress and failures in chill-shock testing noval valves

TABLE 4
Failures in Service Compared with Chill-Shock Failures

RANGE OF SUM OF LAYER-STRESSES IN GROUP	CHILL-SHOCK TEST		LIFE TEST	
	NUMBER TESTED	NUMBER FAILED	NUMBER TESTED	NUMBER FAILED
150 to 300mμ	30	15	30	0
300 to 450mμ	62	9	62	0
450 to 600mμ	42	4	42	0
600 to 750mμ	30	2	30	0
750 to 900mμ	40	4	40	0
Over 900mμ	28	8	28	0

Conclusions

The chill-shock test has been found to reproduce more nearly the types of base failures which are obtained in service and hence its results are considered more functionally significant than those of the B test.

The B test does, however, detect one type of fault also found in service failures, internal crizzles, but the relative occurrence is low. The main purpose of the B test is to detect manufacturing errors.

A direct correlation between the layer stress in the valve base and sensitivity to chill-shock has been found. But direct experiments have yielded no failures on life test, regardless of degree of layer stress. Thus no corresponding correlation has been found between layer stress and failures on life test. The point merits further consideration.

Acknowledgment

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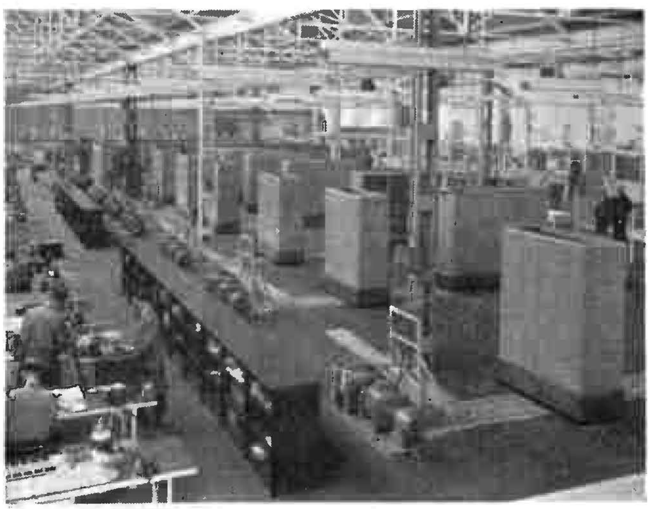
Production Facilities for Computers

A factory which will shortly provide some 300 000sq ft of floor space has recently been undergoing conversion at West Gorton, Manchester, and will allow a production line assembly for the Ferranti Pegasus and Mercury computers. It is claimed that this factory will be, when complete, one of the largest computer production lines outside the United States of America.

The manufacturing activity is supported by research laboratories both in the factory and at Bracknell, near Ascot. These laboratories employ more than 100 development engineers. In addition, there is a Computer Centre at 21 Portland Place, London, where the main body of the Sales Division and a Computing Service are located.

Ferranti Ltd have already manufactured ten large electronic computers and now have additional orders for some thirty-four of these machines of a total value of over £2m. Most of these orders are for the Pegasus and Mercury computers. Some of these are ready for immediate delivery and it is planned that about 25 computers will have been completed and delivered by the end of next year. The rate of output will be more than doubled in the following year. Although this production is at the moment devoted mainly to computers for use in Science Departments of Universities and Research Departments of Industrial Firms and other organizations, the extensive production facilities will make an important contribution to the manufacture of the joint Ferranti/Powers-Samas Integrated Data Processing equipments.



The new West Gorton factory showing Pegasus and Mercury Digital Computers under construction.