THE NEL ORIFICE PLATE PROJECT

by

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S U M M A R Y

This paper reviews previous work to investigate the effect of upstream edge sharpness on the discharge coefficient of orifice plates. It traces the development of Standard requirements for edge sharpness and discusses the need for more guidance in the manufacture and inspection of orifice plates. The main methods in current use for the determination of edge radius are outlined. Finally, the project being undertaken at NEL to provide new information on the effects of edge sharpness and other local defects on the orifice coefficient is described.

1 INTRODUCTION

While the use of orifice plates to measure fluid flow is well defined in the current International Standard[1] there are some aspects of their manufacture and inspection which are not specified in sufficient detail.

One area which gives particular difficulty and, on occasions, grounds for debate is that of the edge sharpness requirement. Most people involved in the use of orifice plates are aware of the great importance of the square edge, but there is no convincing evidence to support the criteria for visual inspection given in various editions of the Standards. For small pipe sizes (less than 125 mm bore) the limiting edge radius of 0.0004d is well nigh impossible to achieve and measure. For larger sizes, the edge sharpness requirement is easier to meet, but the rejection of plates showing 'any peculiarities visible to the naked eye' may be unnecessarily stringent and expensive.

Another deficiency in the current Standard is the quality of surface finish of the downstream face of an orifice plate. Again qualitative, but not quantitative guidance is given.

The NEL orifice plate project was therefore begun to investigate three important topics:

a The effect of upstream edge sharpness to determine at what degree of rounding the orifice coefficient begins to change.

b The effect of local damage to the upstream edge or face of an orifice plate.

c The effect of the finish of the downstream bevel and the surface roughness of the downstream face.

An important part of this project was the survey of previous literature, covering earlier experimental work, and the evolution of the current Standards. Equally important for the manufacture and testing of the orifice plates was the provision of measuring instruments of sufficiently good performance to resolve the small differences in the parameter being investigated and their effect on the orifice coefficient.

2 PREVIOUS WORK

Probably the first relevant reference to edge sharpness effects was in the early 1930s when Professor S R Beitler[2] examined microscopically the edges of plates which gave coefficients that were higher than expected. Although he considered them to be slightly rounded it was not possible to measure the radius of that time without cutting up the plates.

It was not until the 1960s that a major experimental programme was attempted in which measurements of both edge sharpness and the discharge coefficient were measured. Herning[3,4] and his colleagues carried out a programme of tests on a series of different diameter ratio orifice plates installed in meter runs of 50, 100 and later, 150 mm diameter. The edges of the orifice plates were progressively rounded with emery paper and a lead foil method was used to measure the edge radius before each successive calibration.

The results of their work were best summarised in Fig. 6 of reference 4, which is reproduced as Fig. 1 in the present paper. This shows that the effect of the edge depends only on the ratio of the radius of the edge to the orifice diameter.

More recently, Crockett and Upp(5) made further tests using 75 mm (3-inch) diameter plates of 0.2, 0.4 and 0.6 diameter ratio and used the lead foil technique to determine the edge radius.

A little later Benedict(6) and his co-workers investigated the edge effect with 0.5 diameter ratio plates in a 101.6 mm (4-inch) nominal bore test line. Some of the plates were rounded to a radius of about 0.2 mm to represent an extreme case of edge roundness. Both optical and lead foil measurements were used to determine the edge radius.

All the above investigations were concerned with the effect of gross changes of the edge radius. Another series of tests were made by Spencer, Calame and Singer(7) in the 1960s on the production of orifice plates to the then current standard and the errors that could arise if care was not taken and the quality of finish required was not obtained.

3 STANDARDS

The first international standard on orifice plates(8) was published by the International Federation of the National Standardising Associations (ISA) in 1936. It included a graph showing the effects of 'dullness' of the edge. No qualitative description of this 'dullness' was given, but the graph is believed to have resulted from the work of Witte in the early 1930s.

Owing to the difficulty of measuring edge radius, most subsequent Standards seem to have specified that the edge be sharp and left it to the user to satisfy himself that this has been achieved. Little guidance has also been given on how to machine a satisfactory sharp edge, quite a problem for some materials, especially for small orifice diameters.

In the ASME Power Test Code(9) PTC 19.5; 5-1959 it states:

> "e The inlet edge of the orifice shall be square and sharp, free from either burrs or rounding, so that when viewed without magnification a beam of light is not reflected visibly by the edge."

The German Standard DIN 1952 published in 1963 commented that a reflected ray of light from a rounding radius of 0.05 mm is just visible to the naked eye(10). It was concluded that visual inspection could only be justified if the bore diameter was greater than 125 mm at which value the edge radius would be 0.0004d, the criterion given for a sharp edge.

The revised British Standard BS 1042(11) published in 1964 included the same criterion for the sharp edge in the specification of the orifice plate. Clause 54 contained the following requirement:

> "d Upstream edge of orifice. The upstream edge of the orifice shall be square and free from burrs or wire-edges. It may be regarded as square if its radius of curvature nowhere exceeds 0.0004d."

Elsewhere in the same standard some guidance was given on how to produce such an edge. Clause 40 included the statement:

"A high quality of manufacture is necessary to meet the requirements detailed in Sections Seven to Fourteen especially for devices to be used in smaller sizes of pipe. The square edge of orifice plates may conveniently be produced by taking a fine cut, from the centre outwards, after the orifice has been bored; polishing or cleaning with emery cloth is not advisable. There must of course be no burrs or wire edges."

ISO 5167, 1980 which was adopted as BS 1042, 1981[12] incorporated basically the same message in Clause 7.1.6.

"7.1.6 Edges G, H and I

7.1.6.1 The upstream edge G and the downstream edges H and I shall have neither wire edges, nor burrs, nor, in general, any peculiarities visible to the naked eye.

7.1.6.2 The upstream edge G shall be sharp. It is considered so if the edge radius is not greater than 0.0004d.

If $d \geqslant 125$ mm this condition may generally be considered as satisfied by mere visual inspection, checking that the edge does not seem to reflect a beam of light when viewed with the naked eye.

If $d < 125$ mm visual inspection is not sufficient but this condition may generally be considered as satisfied when the upstream face of the orifice plate is finished by a very fine radial cut from the centre outwards.

However if there is any doubt as to whether this condition is satisfied, the edge radius must be actually measured."

Fig. 2 is a reproduction of the drawing of the ISO standard orifice plate and indicates the edges G, H and I referred to the text quoted above. No guidance is given in the Standard on how the edge radius should be measured. A Code of Practice for ISO 5167 is being prepared and this will include brief notes on three suitable techniques, viz lead foil, casting and stylus methods. These, and a few other possibilities, are described in the following section.

4 METHODS OF MEASURING EDGE SHARPNESS

From the foregoing it is apparent that visual inspection is a valuable pre-requisite to a more sophisticated method of measurement even though it cannot give quantitative information. A truly sharp edge will not reflect a beam of light whereas if a line of light is seen it can be concluded that the edge is rounded.

4.1 Optical Method

This method was proposed by Mr A Aschenbrenner of PTB about 1970 and was described by Brain and Reid[13]. A narrow beam of light was directed on to the edge of the plate at an angle of 45° to the tangent, Fig. 3. When viewed through a microscope at 90° to the beam, but in the same plane, the rounded edge was seen as an ellipse. The radius of curvature was estimated by measuring the distance from the intersection of the reflected light beam to the tangent of the ellipse. Unfortunately the amount of light scattering which occurred, blurred the image so the position of the tangent was a matter of judgement on the part of the operator.

The same method was used by Benedict[6] in the mid 70s and good results were claimed.

4.2 Lead Foil Technique

Herning described the lead foil technique for measurement of the orifice edge profile which he developed while working for the Ruhrgas Physical Laboratory in Germany. A small piece of lead foil about 0.1 mm thick was clamped in a holder so that a small piece projected. The holder, and protruding foil, was moved at an angle of 45° against the orifice edge to give an impression which could be projected on to a screen to facilitate measurement. So as not to bend the foil the depth of the impression was kept below about 0.3 mm.

This technique was refined by Jepson and Johnson[14] at the British Gas Corporation Engineering Research Station as some difficulty had been experienced in getting repeatable impressions. They developed the gauge shown in Fig. 4 which could be clamped to the orifice plate along the appropriate marked diameter and a micrometer adjustment used to present the foil to the edge. The lead foil holder could be removed from the gauge for examination using shadowgraphing equipment. Radii down to 0.005 mm could be measured by this method.

4.3 Casting Method

While the lead foil technique produced accurate replicas, they were easily damaged. Gallacher[15] of NEL sought to make a permanent replica which would facilitate microscopic examination. He developed the method in which a liquid cold-forming plastic was poured into a wax or plasticine mold surrounding the location on the orifice plate to be measured, Fig. 5. When hardened, the casting can be removed, sliced and polished to a reference line thus forming a perfect replica of the original edge. Results accurate to 0.005 mm have been obtained.

4.4 Stylus Method

This method is based on a development of the well known 'Talysurf' roughness measuring machine, or its equivalent, which is used to measure the surface finish of plates. By reducing the sensitivity of the machine in the vertical direction to that in the horizontal, a sufficient range can be obtained to examine the edge. A typical record is shown in Fig. 6. Because the roughness of the surface is not of prime interest, and the sensitivity is reduced, it is unnecessary to use a pointed stylus. A small spherical ball, which can be manufactured and measured to fine tolerances, is commonly used being less likely to wear, but of course due allowance must be made for the radius of the ball itself. Magnifications of up to 500 times have been successfully used.

4.5 Assessment of Radius

The lead foil, casting and stylus methods all enable the operator to obtain an enlarged trace of the edge itself. As can be seen from the various illustrations, this is seldom a true circular arc and the estimation of the mean radius depends to some extent on the skill and experience of the operator. Sets of standard radii enlarged to the correct degree of magnification and printed on transparent plastic film can be used as overlays on the traces of the edge in order to assist with the estimation of the radius. However, as those who have tried this procedure will appreciate, this is not a simple operation.

Some of the instruments used for the stylus method facilitate the use of curve fitting routines. Sets of x and y coordinates defining the locus of the stylus can be down-loaded to a micro-computer and the best fit circle obtained for the curved region. Care has to be taken to define the length of trace to be fitted as the points of tangency may not be clear. This may be helped by examining a plot of the residuals obtained after subtracting the best fit circle from the points selected. It is also a simple matter to allow for the radius of the stylus.

It should perhaps be stressed that this curve fitting routine is intended to augment rather than replace the visual assessment of edge sharpness with the aid of overlays if appropriate. The main purpose is to accomplish the same task, but to remove some of the subjectivity from the assessment.

5 NEL EQUIPMENT AND TEST PROGRAMME

As all known previous work was limited to pipes of diameters of 150 mm or less it was decided to base the current measurements on 300 mm (12-inch) nominal bore pipe as being more representative of the sizes commonly used for gas transmission. Three diameter ratios were chosen; 0.4, 0.6 and 0.75, again typical of those in use, giving orifice bores of 120, 180 and 225 mm respectively. A Junior orifice fitting was chosen to facilitate repeated removal and replacement of the test plates.

The flow tests are being made in air using a set of three venturi nozzles in free inlet condition as reference flowmeters. Each nozzle is sized to correspond to one of the three orifice plate diameter ratios in order to give comparable ranges of differential pressure which is being measured using Betz manometers.

In addition to the usual measurements of orifice bore, concentricity, thickness, surface roughness etc, the edge sharpness is being measured at eight positions round the orifice using both the stylus method and by means of cast plastic replicas. NEL has recently bought a Rank Taylor Hobson Talycontor instrument for this purpose, although the replica casting technique has been available for several years.

The first phase of the test programme is to investigate the effect of upstream edge sharpness. Beginning with a radius of about 0.0001d one plate of each diameter ratio is being successively rounded in increments towards a radius in excess of 0.001d and the plate calibrated each time.

The second phase will investigate the effect of local damage introduced to the upstream edge and gradually extended round the circumference. Calibrations will be carried out to determine how extensive the damage has to be before the orifice coefficient is significantly affected.

The third phase will comprise a series of tests to investigate the effect of imperfections on and roughness of the downstream side of the orifice plate.

This work is currently at an early stage and is expected to take a further 12 months to complete.

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LIST OF FIGURES

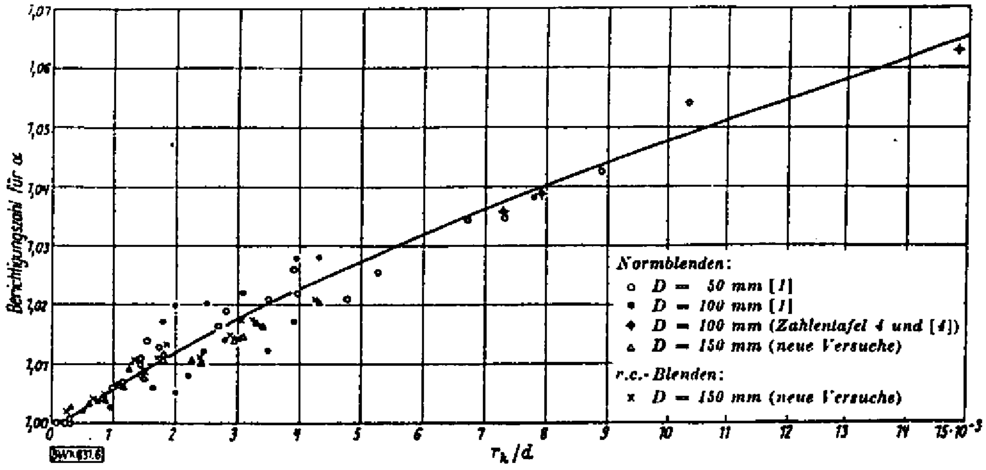

FIG 1 MULTIPLIERS FOR FLOW COEFFICIENT

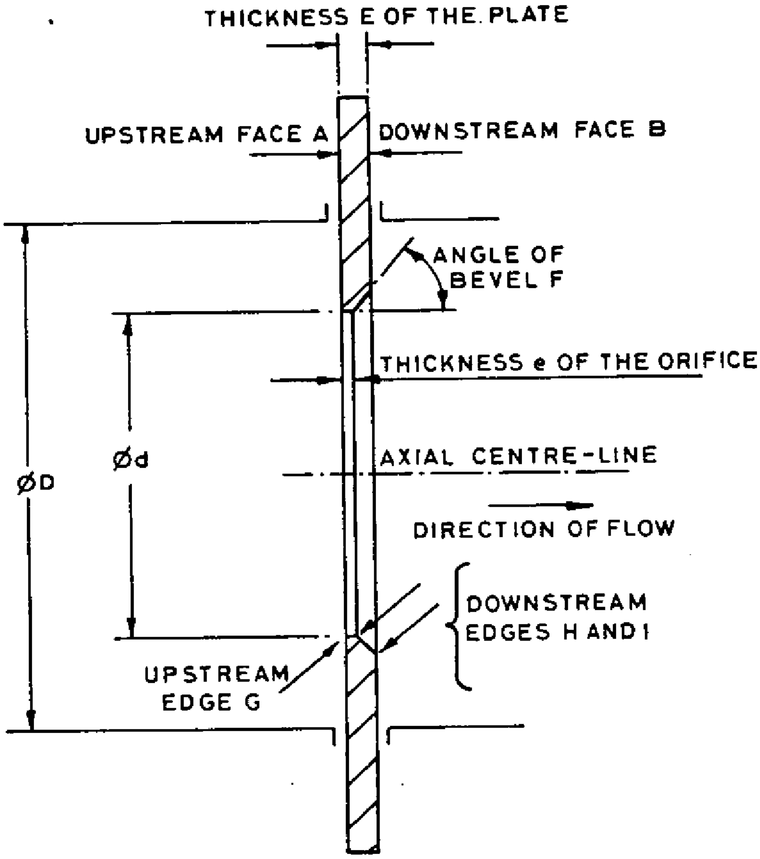

FIG 2 STANDARD ORIFICE PLATE

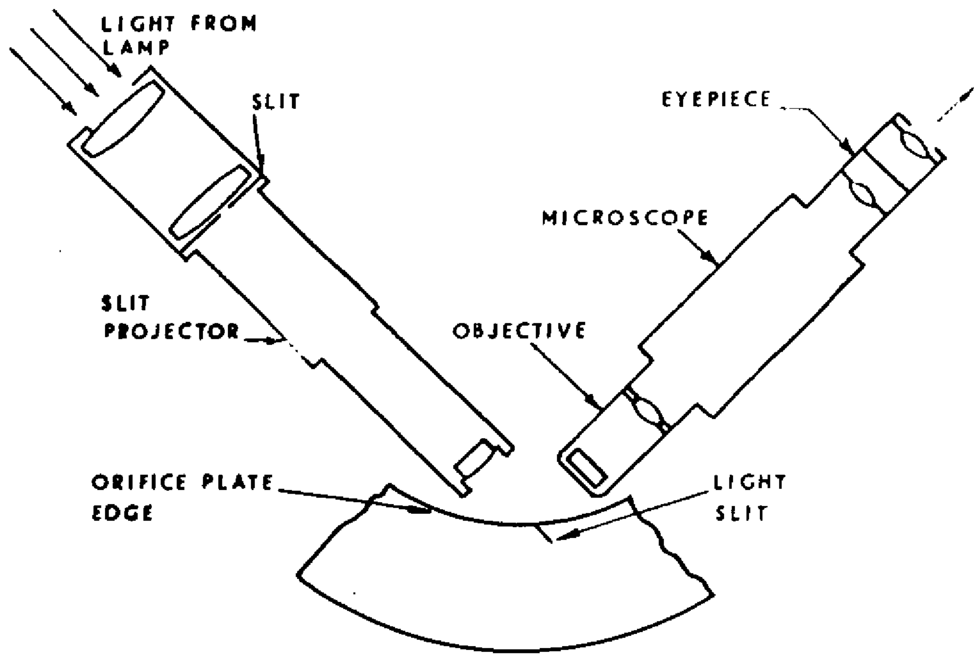

FIG 3 APPARATUS USED FOR OPTICAL METHOD

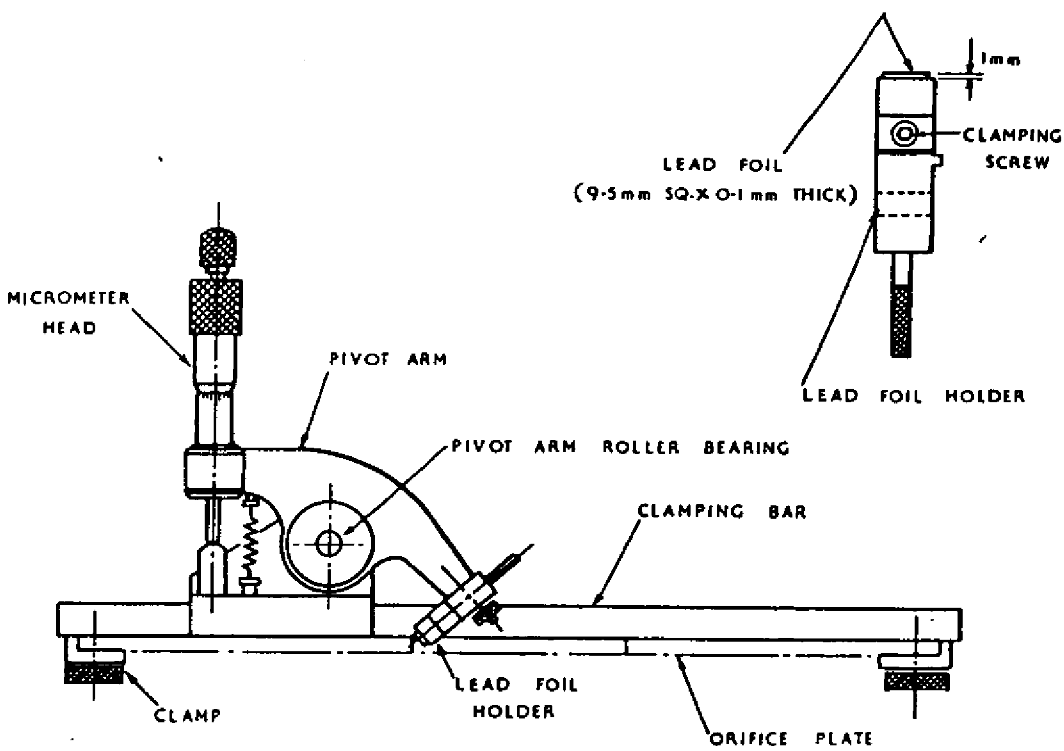

FIG 4 GAUGE USED IN LEAD FOIL METHOD

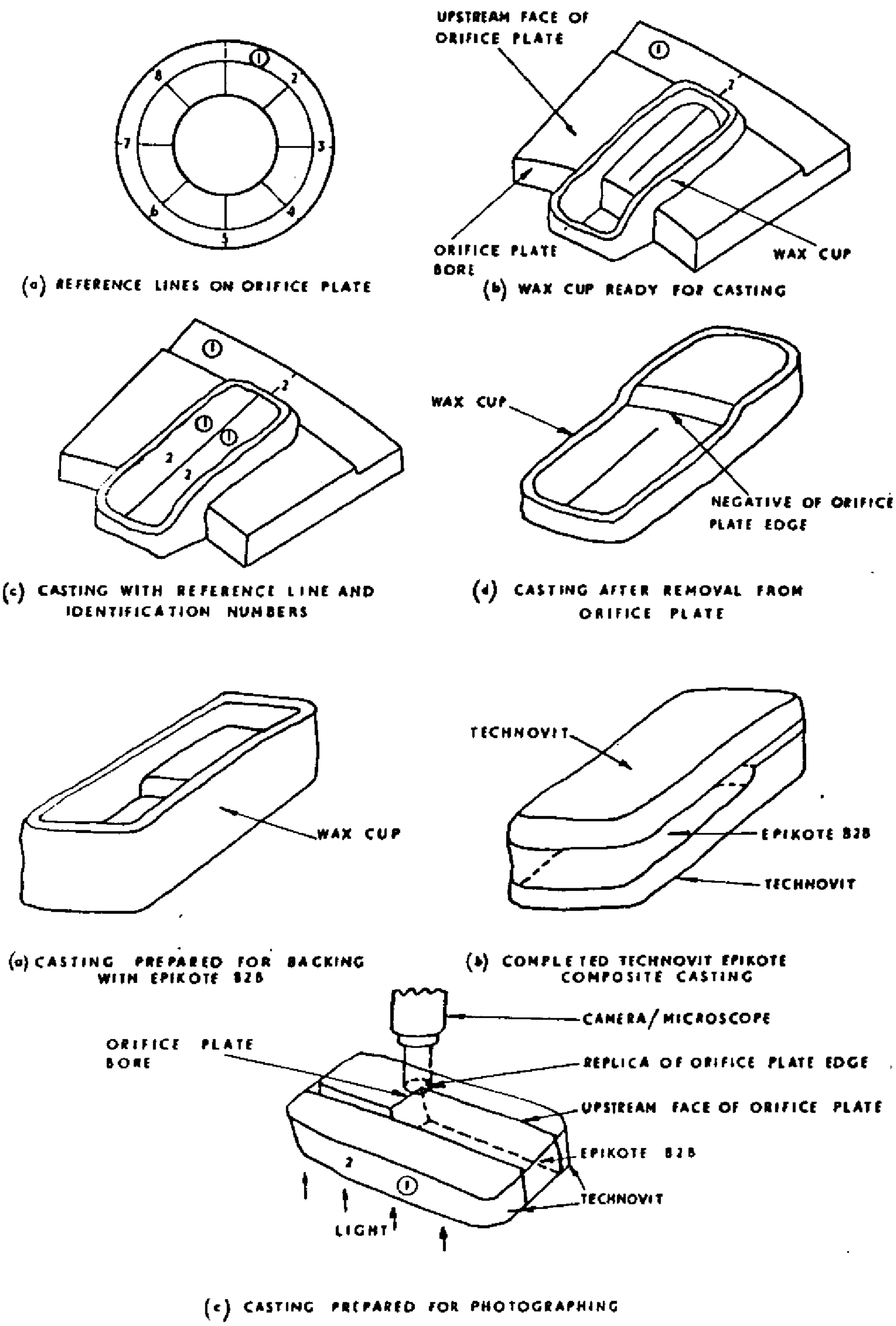

FIG 5 STAGES OF THE CASTING METHOD

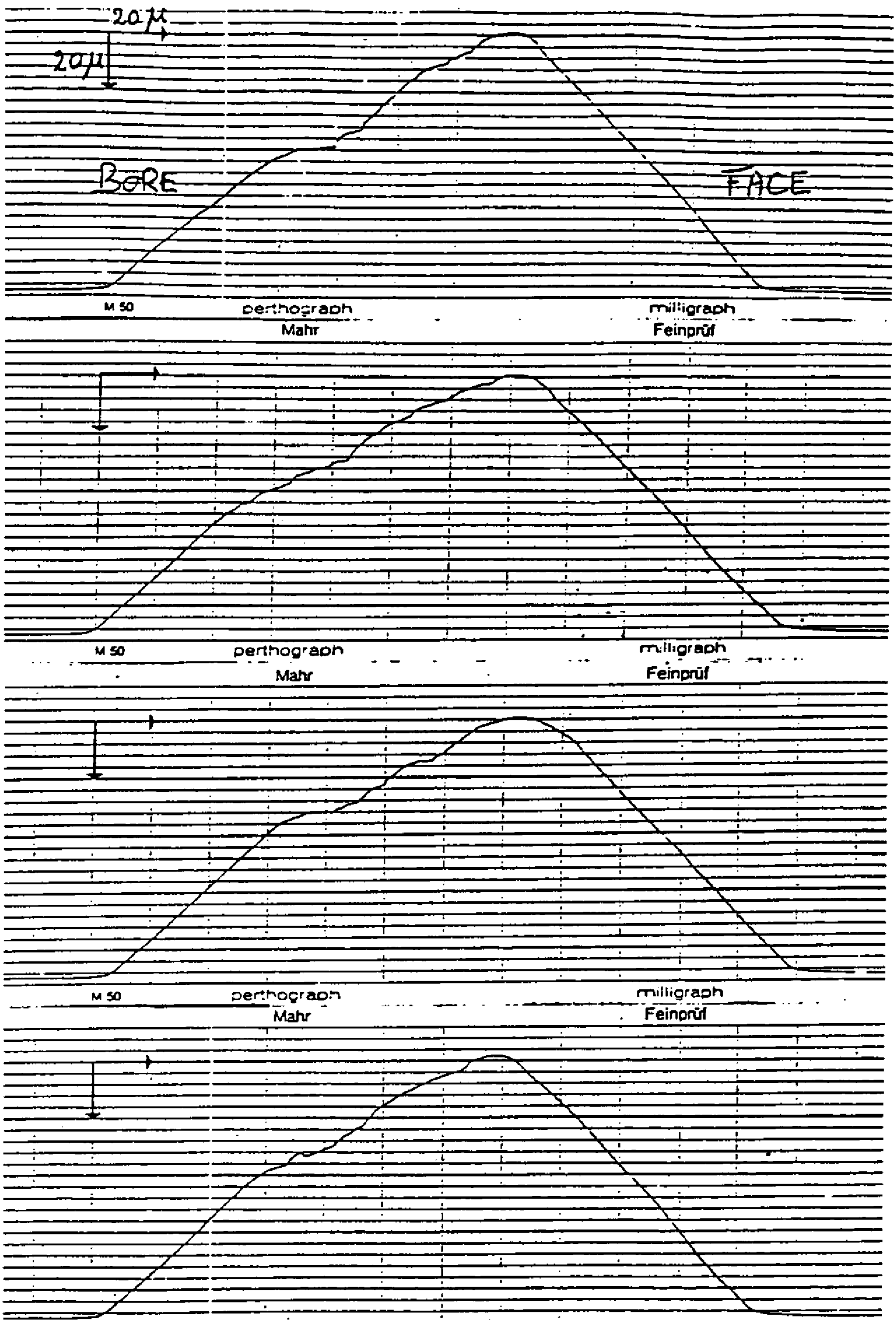

FIG 6 TYPICAL RECORD FROM STYLUS METHOD