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CRANFIELD HIGH PRECISION UNIVERSAL MEASURING MACHINE

CONTENTS

INTRODUCTION

The extensive programme of research undertaken by the Department of Production and Industrial Administration at the College of Aeronautics, Cranfield into Metrology and Precision Engineering has shown the need for a Very High Precision, Very Universal Measuring Machine. Discussions with other organisations working on complex problems in Engineering Dimensional Metrology have confirmed this view. In particular, very valuable suggestions have been made by senior officers from N.P.L., R.A.E. Farnborough, Inspectorate of Ministry of National Defence and the Inspection Panel of the Gas Turbine Co-ordinating Committee.

The whole of the data collected from the above and other sources was analysed and an attempt was made to prepare a specification for the ideal machine. A preliminary design of a possible prototype machine that appeared to satisfy the above specification was made and this was discussed with most of the organisations mentioned above. It appeared that the development of a machine on the lines suggested would make a significant contribution to progress in Engineering Dimensional Metrology and consideration was given to possible methods of implementing the scheme. An application was submitted to the Science Research Council for a grant to undertake a detailed feasibility study into the proposals which had emerged from the above long and helpful discussions. A grant was made by the Science Research Council and work based at Cranfield has proceeded with the financial support provided by the S.R.C. grant. The present report is designed to show the results that have emerged from the above study and to indicate in some detail the range of machines that could be made from the basic concepts set out in the original proposals.

SPECIFICATION

The following is a brief outline of the specification to which the machine has been designed. It is anticipated that if all the requirements in the specification are met, the overall measuring accuracy of the machine will be that the indicated or recorded value given by the machine will be within plus or minus 0.4 microns in each of the three mutually perpendicular axes for parts embraced in a 500 mm (20") cube and half the above value in a 250 mm (10") cube.

1. The part undergoing inspection must be mounted in a manner that prevents movement in excess of 0.2 micron in any direction between the frame formed by the ideal lines along which the moving elements of the machine operate and the work being measured.

2. Provision must be made for the part to be adjusted during the setting up operation in the following manner:-

   (i) Adjustment to make predetermined datum faces on the part to be parallel to the X, Y, or Z axes of the machine.

   (ii) Rotation of the part about a fixed vertical axis in a plane that is parallel to the plane formed by the X and Y axes of the machine.

3. Movements of the measuring probe in relation to the work to be measured to be provided as follows:-

   (i) Along X axis in a line that is enclosed within a straight envelope 0.2 micron diameter 250 mm length of movement and half the above amount in any 100 mm length of movement and half the above amount in any 100 mm length of movement. In the prototype model, to be built as a feasibility study, the X axis to be 750 mms long but the machine to be designed so that this axis can be extended, when required, up to a length of 10 metres on other models.

(ii) Along Y axis for a distance of 500 mms in a line that is in the same horizontal plane as the X axis and at 90 degrees ± 1 second to that axis and straight to the same tolerance.

(iii) Along the Z_1 and Z_2 axes for distances of 250 + 250 mms in lines that are at 90 degrees ± 1 second to the plane formed by the X and Y axes and straight to the straightness tolerance specified above.

(iv) Further requirements to be satisfied concerning the movement on the Z_1 and Z_2 axes are:-

(a) Z_1 to be 250 mms of movement in a fixed vertical slide and along the line that is enclosed in a straight envelope 0.2 micron diameter.

(b) Z_2 to be 250 mms of movement by a circular member capable of moving along a straight line to the straightness tolerance specified above and rotating about an axis that is contained in a straight cylinder 0.1 micron diamet er.

(c) The above circular member (Z_2) to be provided with angular adjustment through 90° clockwise to 90° anti-clockwise in increments of 30 seconds of arc about a horizontal axis and in a plane that is parallel to Z_1 and Z_2 axes and at 90 degrees ± 2 seconds.

Note: The whole of the above conditions to be satisfied when the measuring probe is in any of the positions specified as within the design capacity of the machine.

4. Provision to be made for the cylindrical member on the "Z_2" axis to be rotated in synchronisation with a circular or strip recording chart and when required to be traversed in an axial direction at a predetermined rate in relation to the rate of rotation.

5. Friction in all directions for which motion is provided to be small. Coefficient of friction for very slow rates of motion to be less than 0.0001. Movement along X, Y, Z_1 and Z_2 axes to be made when required in increments of 0.2 micron.

6. Stiffness to be high in all directions except direction of motion.

7. The machine to be provided by a measuring unit attached to the lower end of the spindle forming the Z_2 axis and designed to provide the following:-

   (i) Digital readout from predetermined datum positions.

(ii) Facility to move to predetermined datum radius by open loop control.

(iii) Facility to give analogue output on scale and pointer type display or to provide recordings of errors of roundness on polar co-ordinates on a circular chart or rectangular co-ordinates on a strip type recorder and for inspection of more complex parts.

(iv) Facility to impulse output reader (punched paper tape).

8. Movement along X, Y and Z axis to be given by numerical electronic display reading to 0.2 micron.

9. Machine to be designed on a unit schedule basis in which the 10 alternative models shown on the attached schedule are available.

10. Machine to be designed to receive instructions from a predetermined number and types of tape input including the following given as examples only:-

(i) Point to point on X, Y and Z_1 axes.

(ii) Point to point on X, Y, Z_1 and Z_2 axes.

(iii) Point to point on X, Y and Z_1 axes and rotation on Z_2 axis.

(iv) Point to point on X, Y, Z_1 and Z_2 axes and rotation on Z_2 axis.

(v) Continuous path for X, Y and Z_1 axes.

(vi) Continuous path for X, Y and Z axes and rotation of Z_2 axis to keep movement of measuring probe normal to surface being measured.

(vii) Continuous path for X, Y, Z_1 and Z_2 axes.

(viii) Continuous path for X, Y, Z_1 and Z_2 axes and rotation of Z_2 axis to keep movement of measuring probe normal to surface being measured.

(ix) Point to point on X, Y and Z axes, open loop control of radius of measuring surface of measuring probe to predetermined radius and rotation of Z_2 for roundness test of circular holes.

(x) Point to point for X, Y, Z_1 and Z_2 axes, open loop control of radius of measuring surface of measuring probe to predetermined radius and rotation of Z_2 for roundness test of circular holes.

(xi) As (ix) except rotation and transverse motion of Z_2 axis to be provided for cylindricity test of circular holes.

(xii) As (x) except rotation and transverse motion of Z_2 axis to be provided for cylindricity test of circular holes.

(xiii) As (xi) but inclusion of continuous path inspection of form described in (vi).

(xiv) As (xii) but inclusion of continuous path for inspection of form as described in (viii).

DESCRIPTION OF MACHINE

The machine has to be designed on a unit schedule basis, in which at least 10 alternative models can be produced, ranging from a simple 3 axes, manually operated system to a complex tape controlled and fully automatic machine.

The basic units which are common to all machines as shown in Fig. 1 are:-

1. The bed.
2. The saddle.
3. The beam.

The bed is designed to provide a base which supports the saddle and beam in a manner in which distortion due to movement is reduced to the absolute minimum. The bed also provides the guiding member for the X axis. The bed is made from a close grained, densified cast iron (grade 17) and is mounted on the foundation at four separate points. Each point of support has its own 3 kinematic locations and the ribs in the bed are displaced so that the 12 overall support points are unformly distributed (Fig. 2). In the finally assembled machine the bed will be held down to the foundation through the four main support points by pretensioned securing bolts.

The saddle is again made from grade 17 cast iron and designed to give support to the beam moving along the Y axis and in a manner that provides straight line motion with minimum deflection to the structure.

The beam design is based on an optimum structures principle using a uniform stress value throughout the structure which gives maximum stiffness and minimum deflection for minimum weight. The beam is of welded construction from EN9 steel and incorporates a flat vertical face to which the various types of Z axis can be attached.

ACTUATION. The actuation to the 'X' and 'Y' axes is achieved by means of a piston and cylinder, in which the piston is hydrostatically supported in the cylinder, as shown in Fig. 3. This enables the stick-slip phenomenon which normally occurs between the piston seal and cylinder to be completely eliminated and hence fine positioning is readily achievable, either with open or closed loop control.

The actuation for the linear 'Z' axis is achieved by using fine pitch lead screws in which back-lash is eliminated pneumatically and actuation is effected by means of a stepping motor drive which can be controlled to rotate at 1.8° intervals.

The actuation for rotating the measuring probe about the 'Y' plane is again achieved by means of a stepping motor and fine and very accurate angular positioning is effected by using suitably designed multi-radial locating members.

Spindle rotation is also achieved by means of a stepping motor, and the spindle is mounted on air bearings.

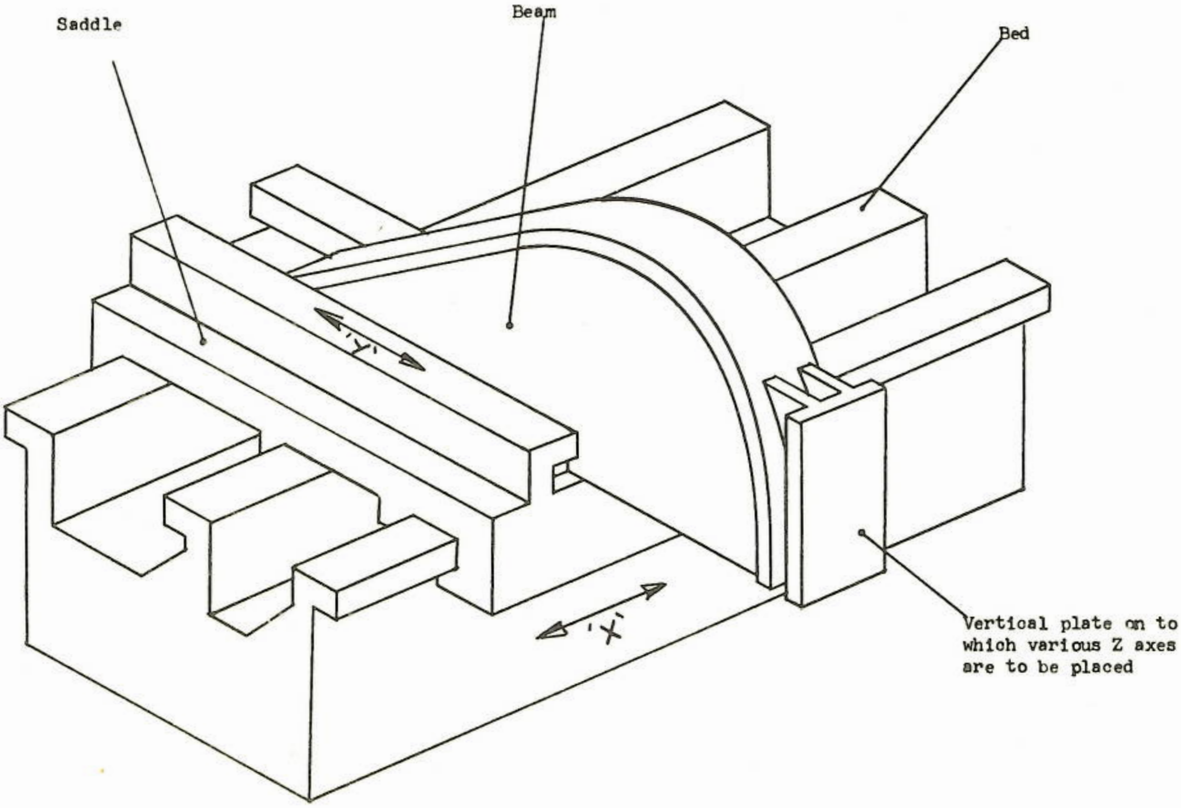
MEASUREMENT. Linear displacements in each of the three axes are measured using a laser interferometer based on the system developed by Dr. Rowley of the N.P.L. (Fig.4). The lasers to be used are two Elliott helium-neon frequency stabilised lasers giving a light wavelength of 6328 Å (24.9 μin), which can be readily sub-divided into quarter wavelengths for actual measurements. One laser is to be used for the interferometers in the X and Y axes, and the other one is to be used for the interferometers in the Z_1 and Z_2 axes. The resultant fringes produced by the interferometers are counted photo-electrically and stored in a counter, with the readout display in octal units.

TYPES OF MACHINES AND COMPONENTS

It has been stated that at least 10 basic models could be designed of various complexity, ranging from a simple 3 axes, manually operated system to a complex, tape-controlled and fully automatic machine.

The main feature changes occur in the Z axis, and a number of the measuring machines of differing complexity have been drawn up and are illustrated together with some typical components which can be inspected.

The manually operated machines are numbered from 1 to 8, etc., and the tape-controlled machines are numbered 50 to 53. Component 59, 60, 61, 62 and 63 are typical components which can be inspected on some of the measuring machines when fitted with special adaptors.



Saddle
Beam
Bed
'Y'
'X'
Vertical plate on to which various Z axes are to be placed

FIG. 1

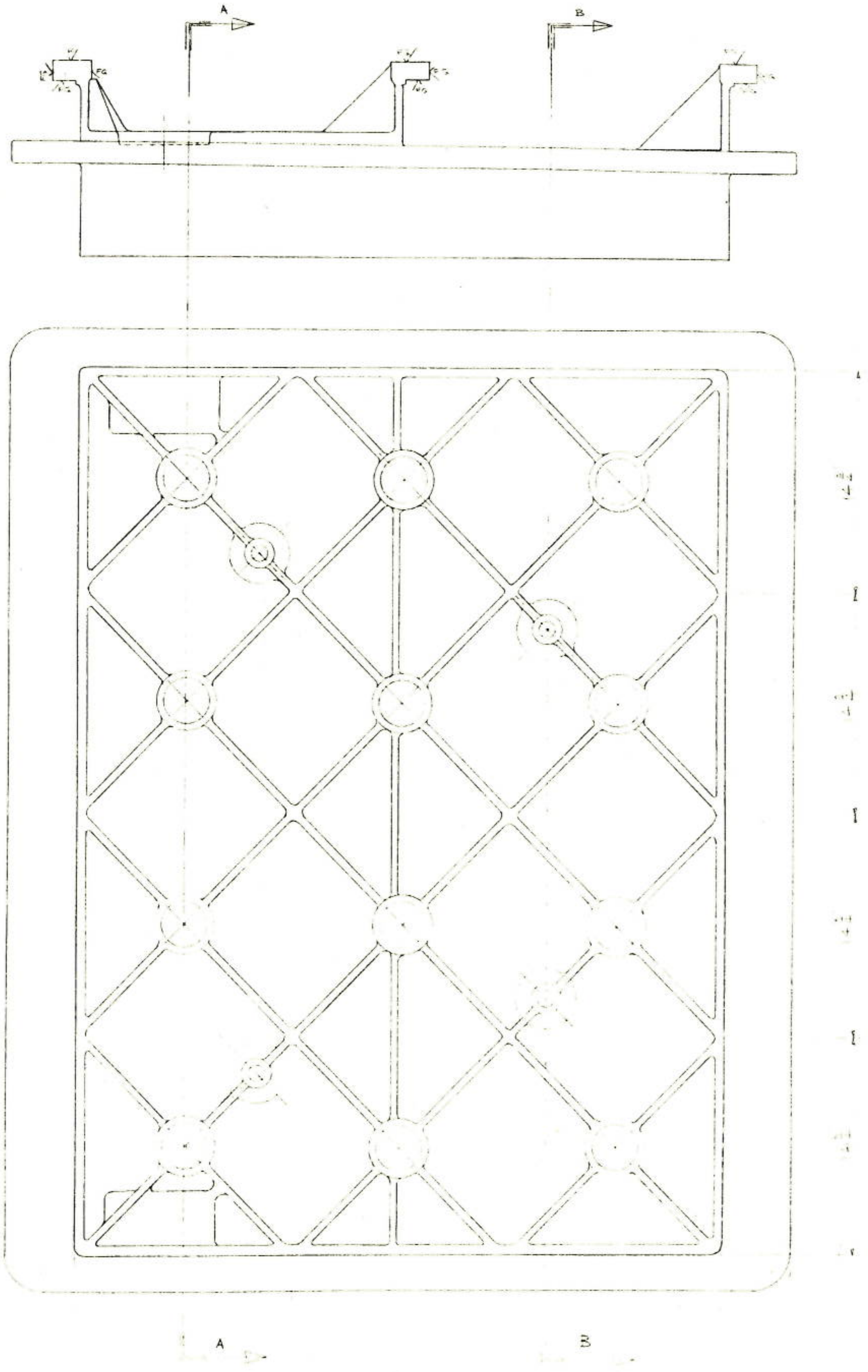
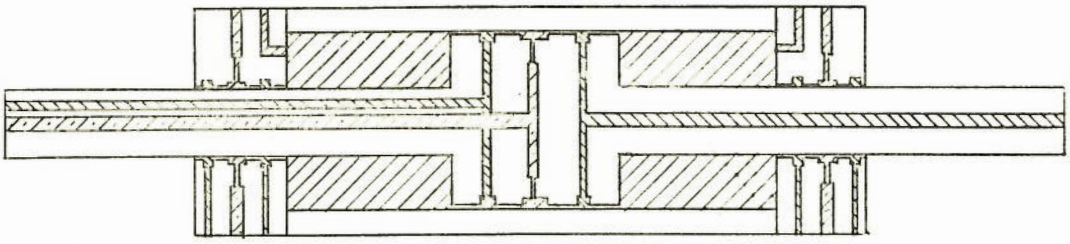
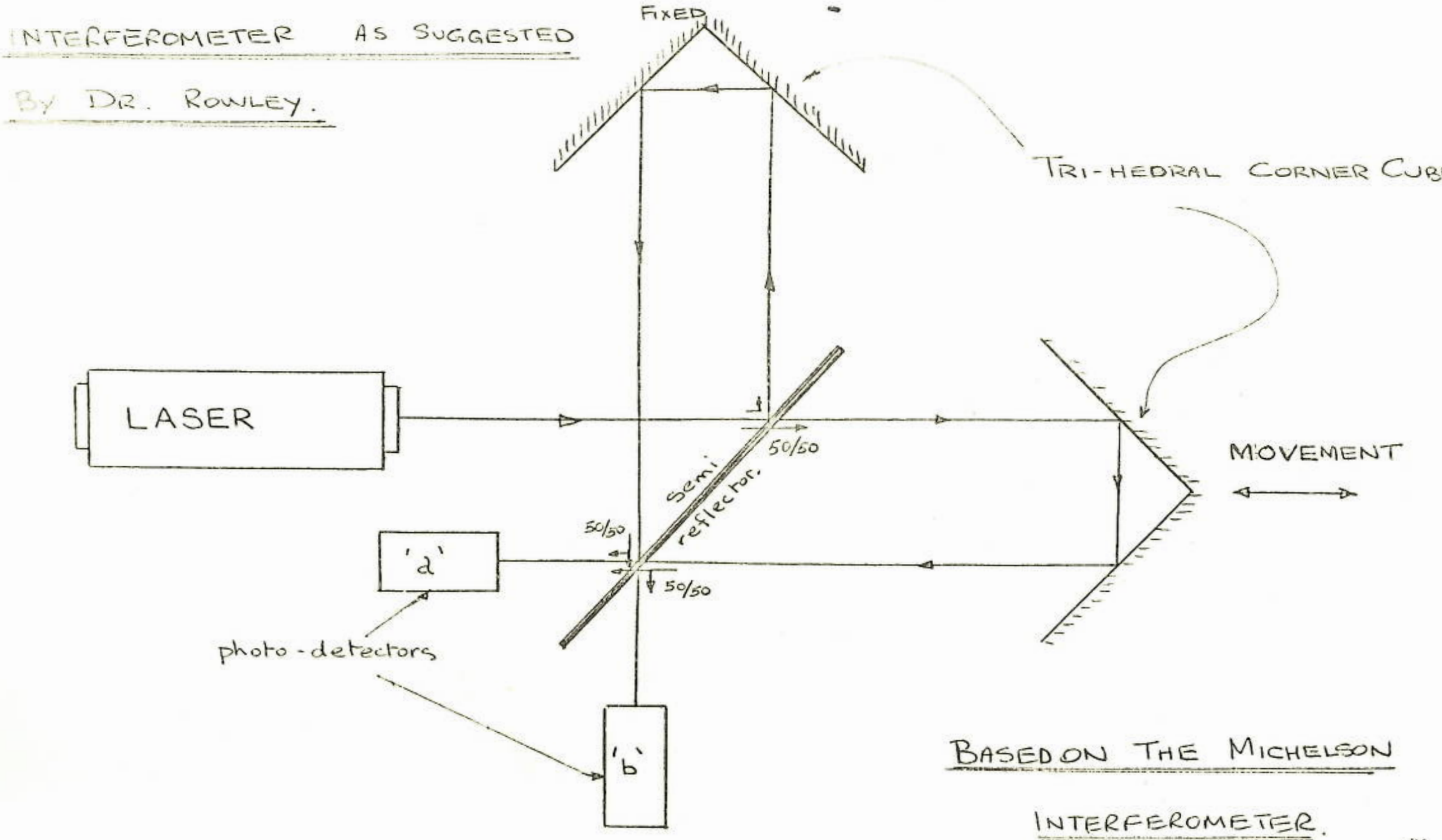


FIG 2



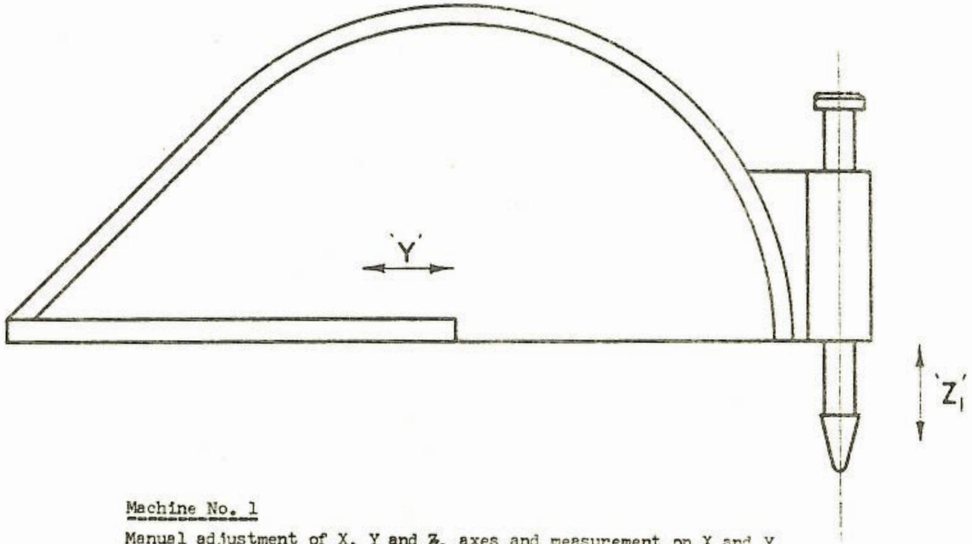
High pressure bearing oil   Control oil   Return oil

FIG. 3 DIAGRAMMATIC SECTION SHOWING OIL SERVICES & RETURNS



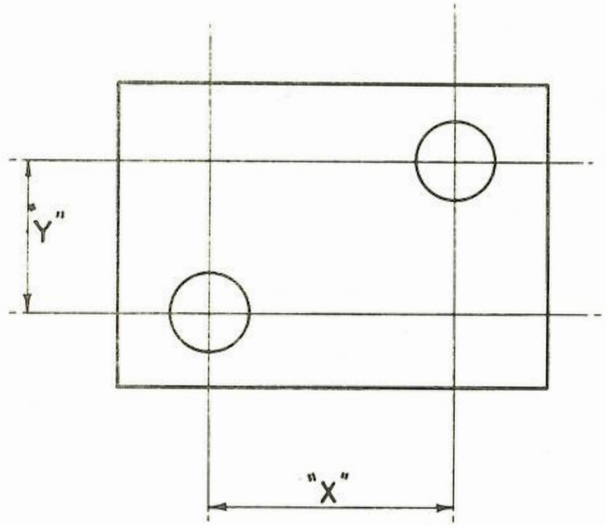
BASED ON THE MICHELSON INTERFEROMETER.

FIG 4.



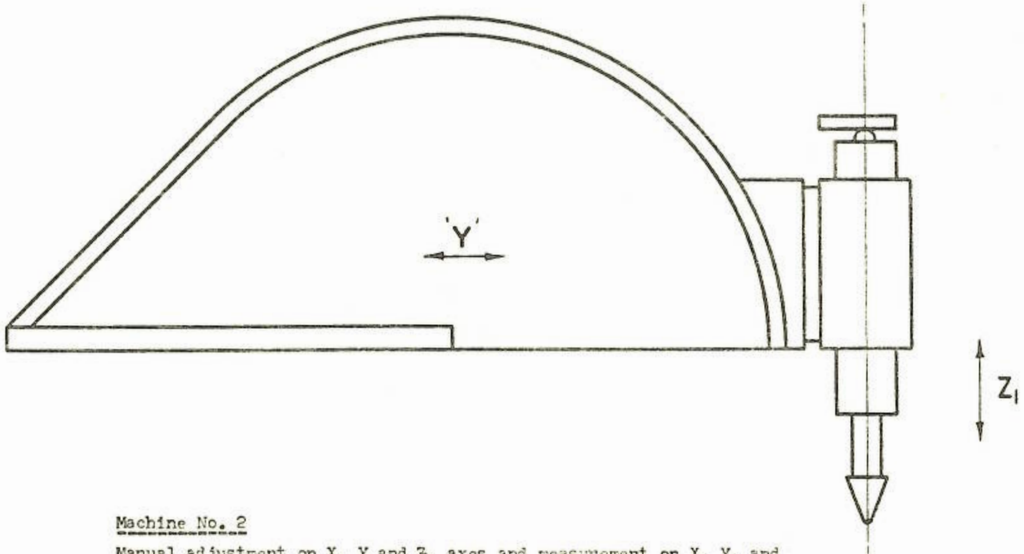
Machine No. 1

Manual adjustment of X, Y and Z_1 axes and measurement on X and Y axes.



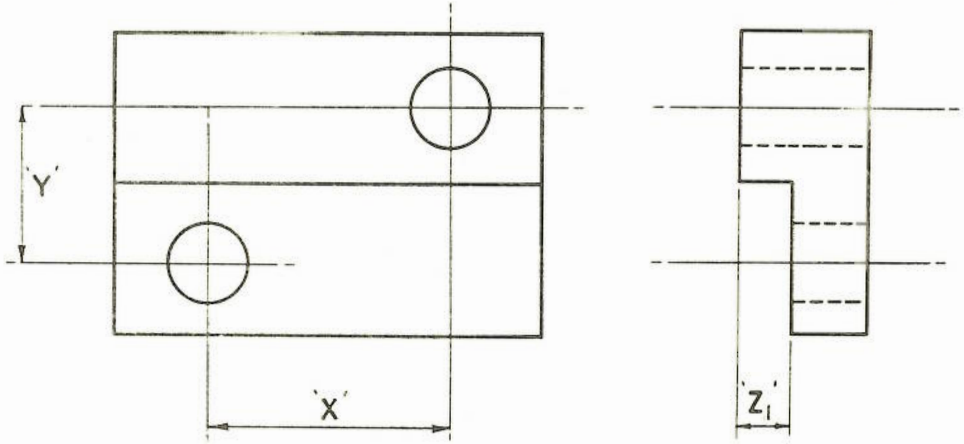
Component 1

Showing measurement on 'X' and 'Y' axes.



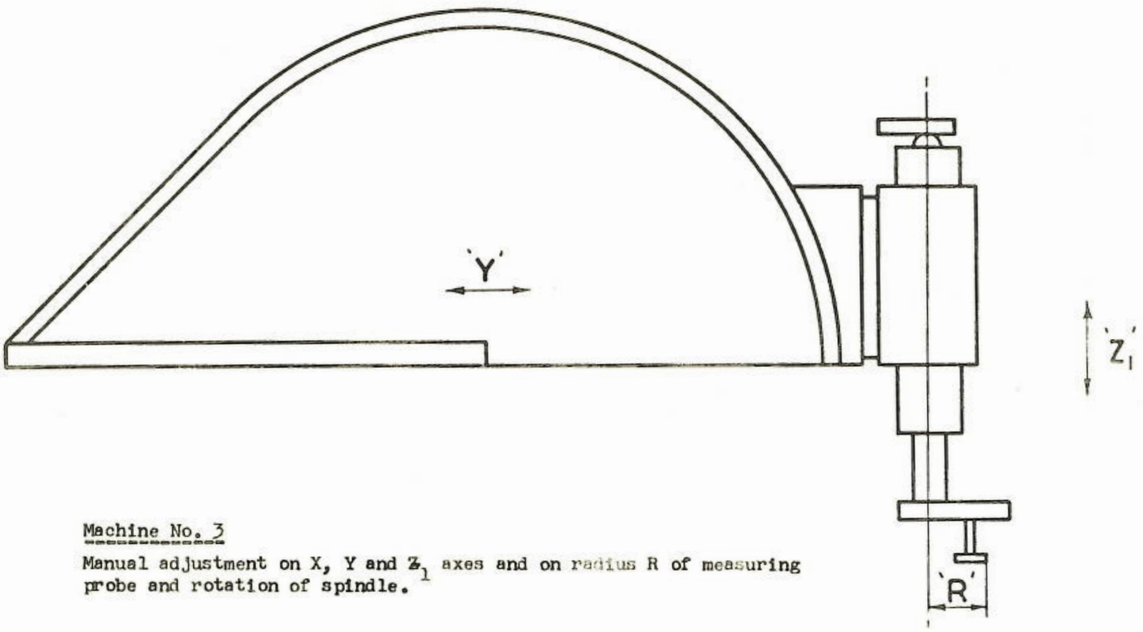
Machine No. 2

Manual adjustment on X, Y and Z_1 axes and measurement on X, Y, and Z_1 axes.



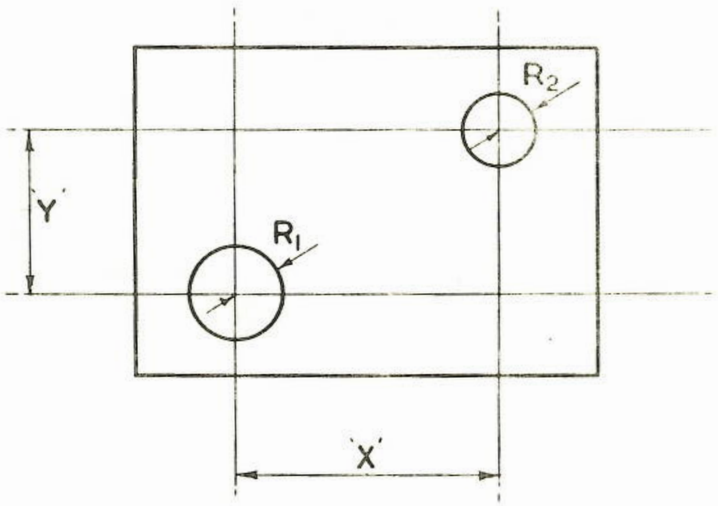
Component 2

Showing measurement on 'X', 'Y', and 'Z_1' axes.



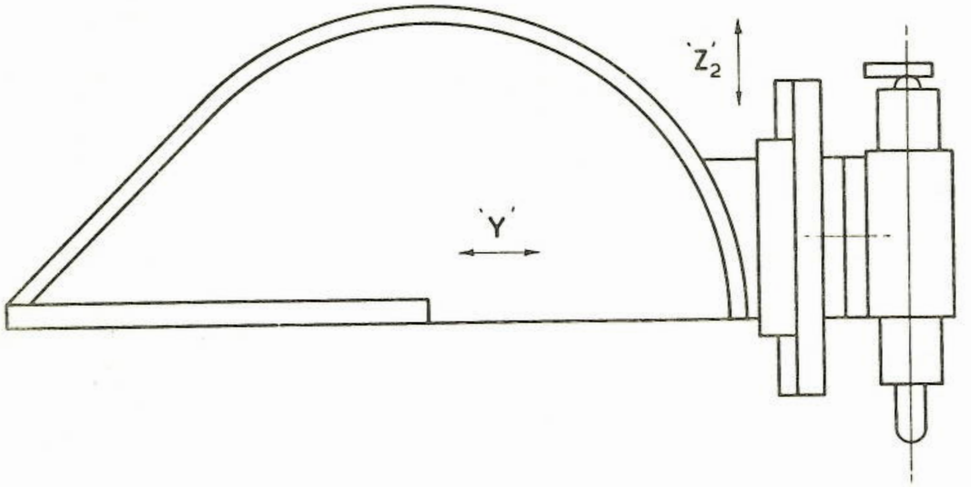
Machine No. 3

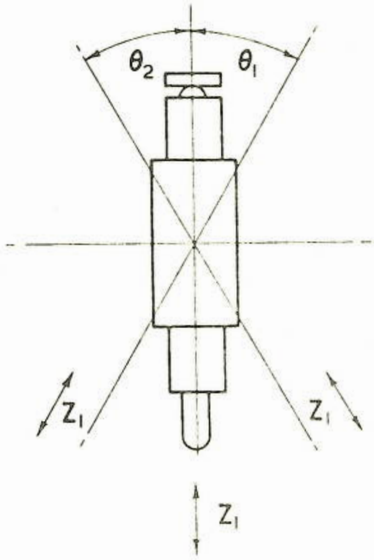
Manual adjustment on X, Y and Z_1 axes and on radius R of measuring probe and rotation of spindle.



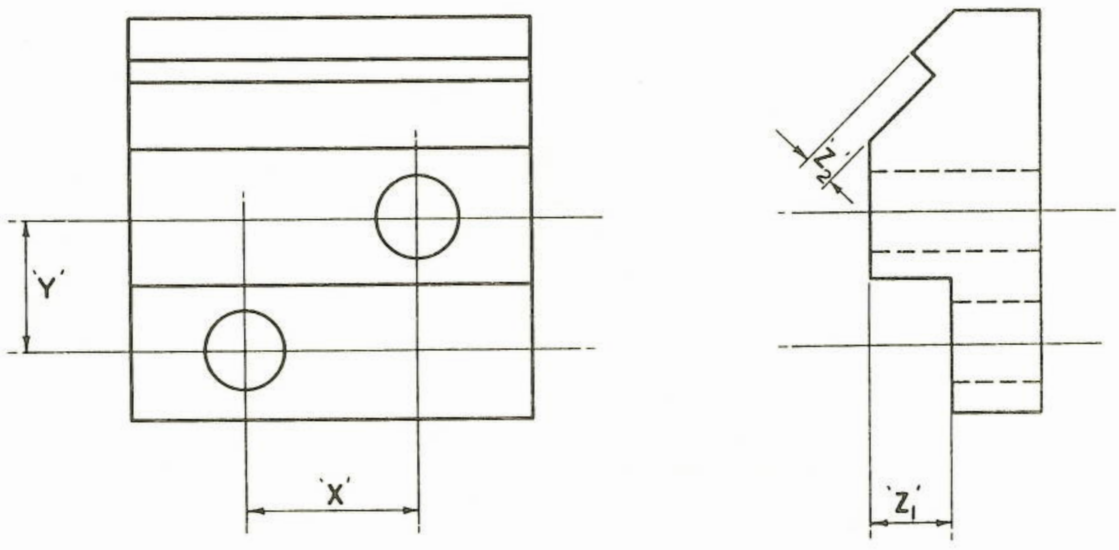
Component 3

Showing measurement on 'X' and 'Y' axes and on radii R_1 and R_2.

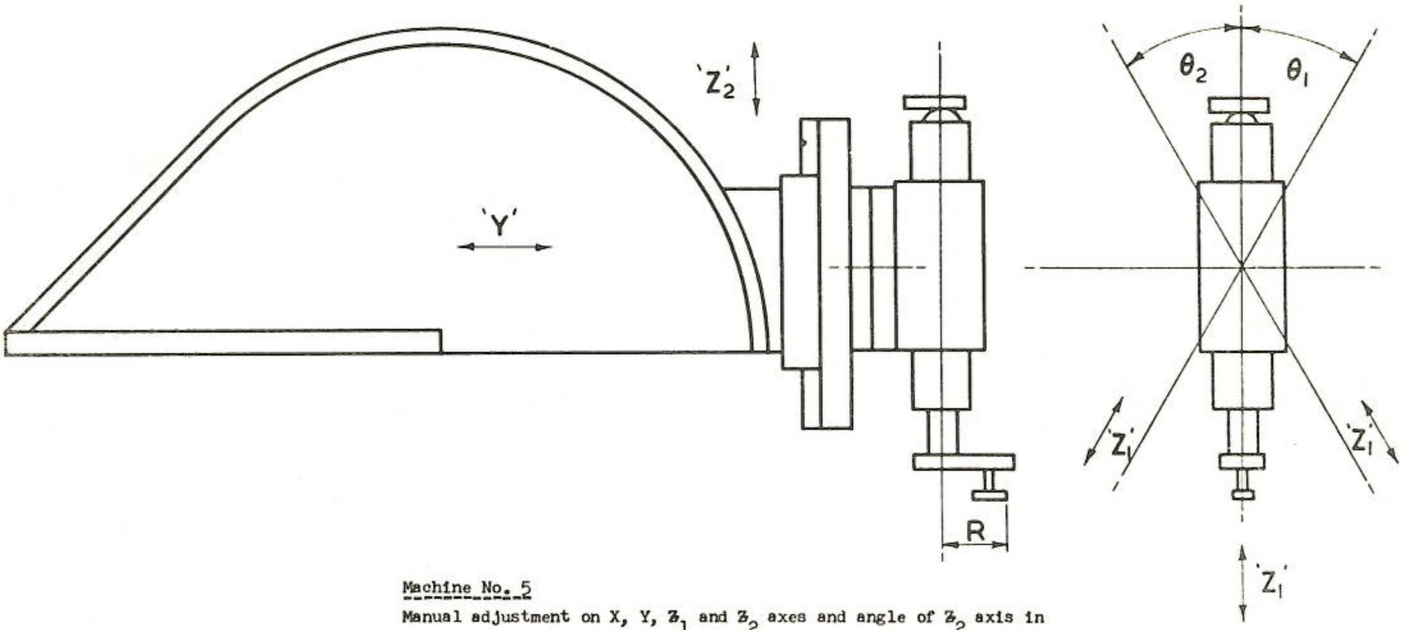




Machine No. 4
Manual adjustment on X, Y, Z_1, Z_2 axes and angle of Z_1 axis in increments of 0° - 30 through 90° clockwise and 90° anti-clockwise from vertical measurement on X, Y, Z_1 and Z_2 axes.

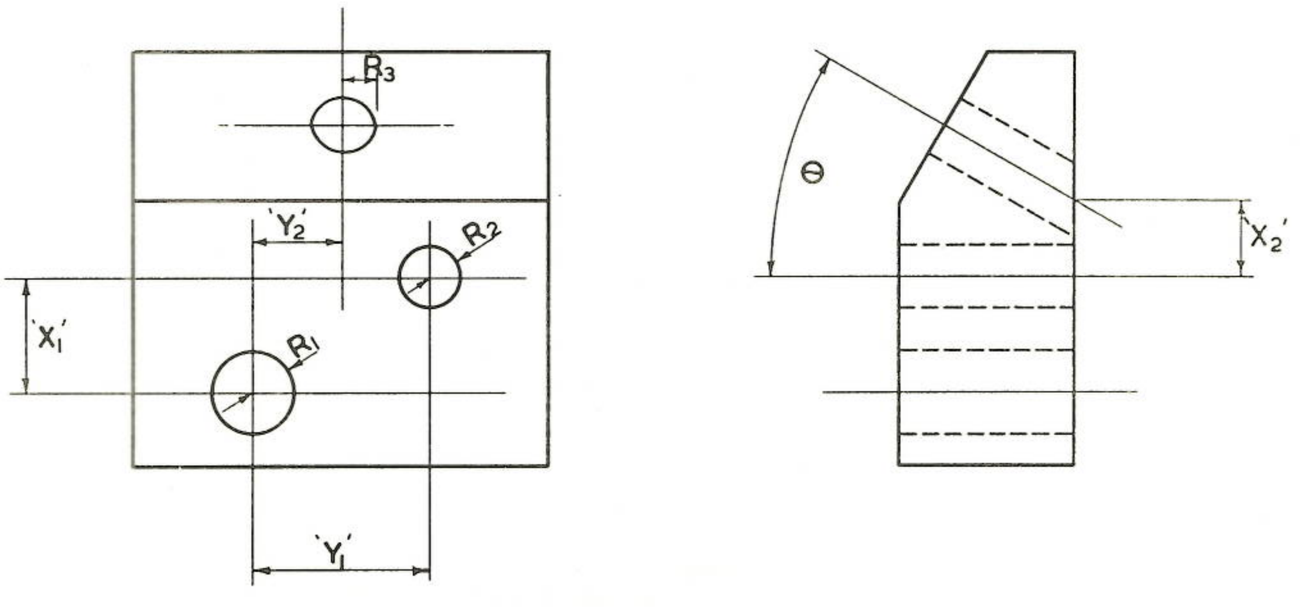


Component 4
Showing measurement on X, Y, Z_1 and Z_2 axes.



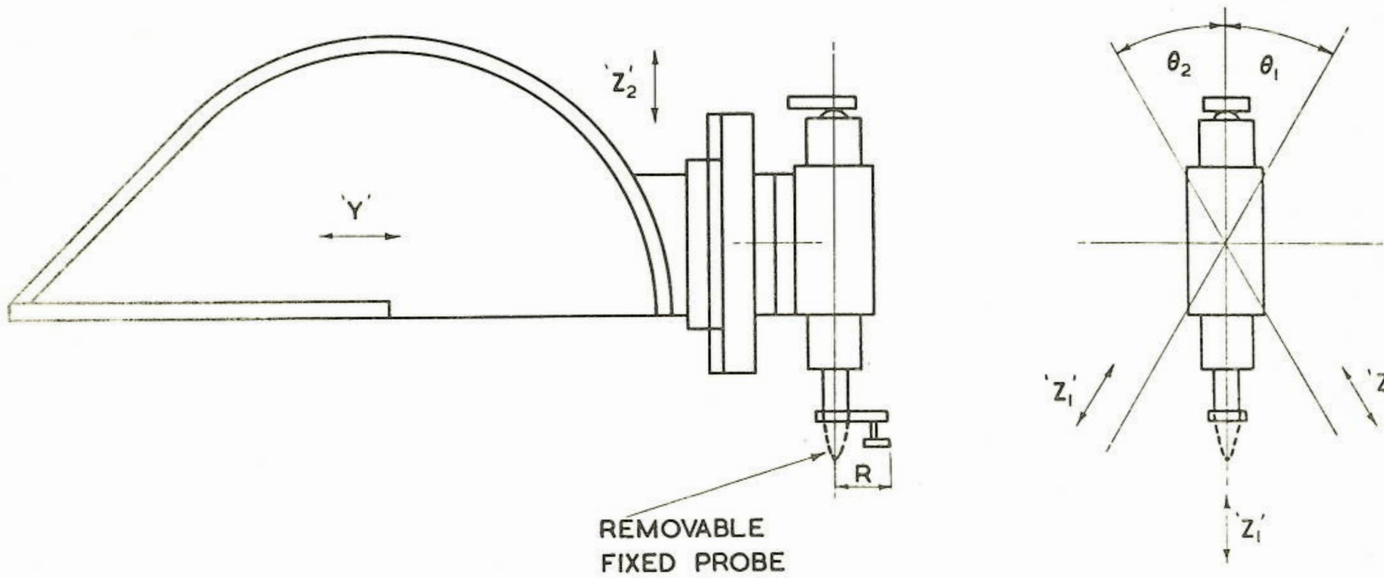
Machine No. 5

Manual adjustment on X, Y, Z_1 and Z_2 axes and angle of Z_2 axis in increments of 0°-30' through 90° clockwise and 90° anti-clockwise from vertical. Manual adjustment of radius prescribed by measuring probe and on rotation of spindle measurement on X_1, X_2, Y_1 and Y_2 axes and on radii R_1, R_2, R_3 and angle θ.



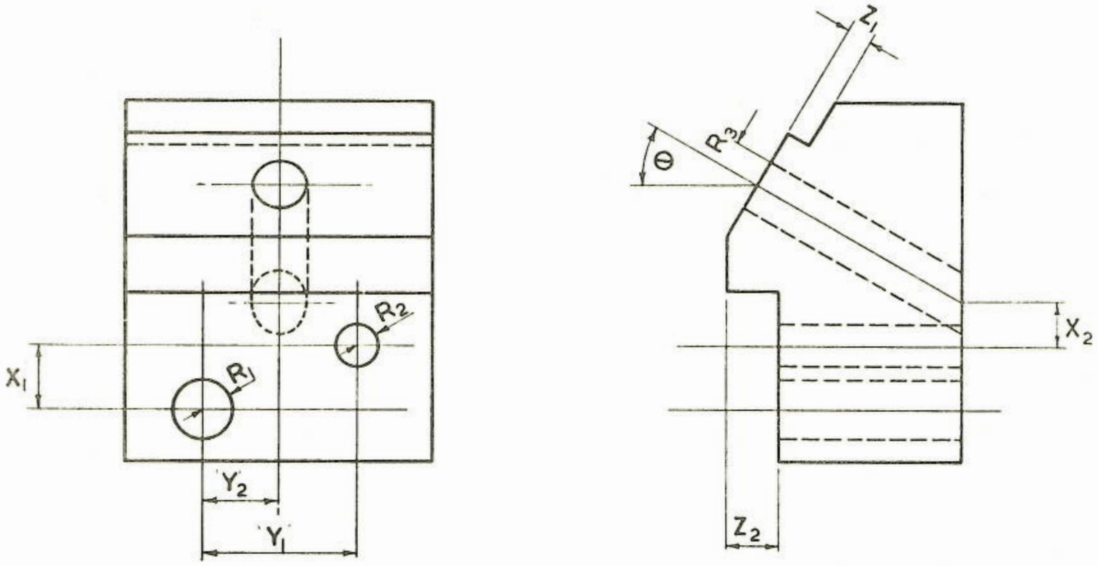
Component 5

Showing measurement on X_1, X_2, Y_1, Y_2 axes, and on radius R_1, R_2, R_3 and on angle θ.



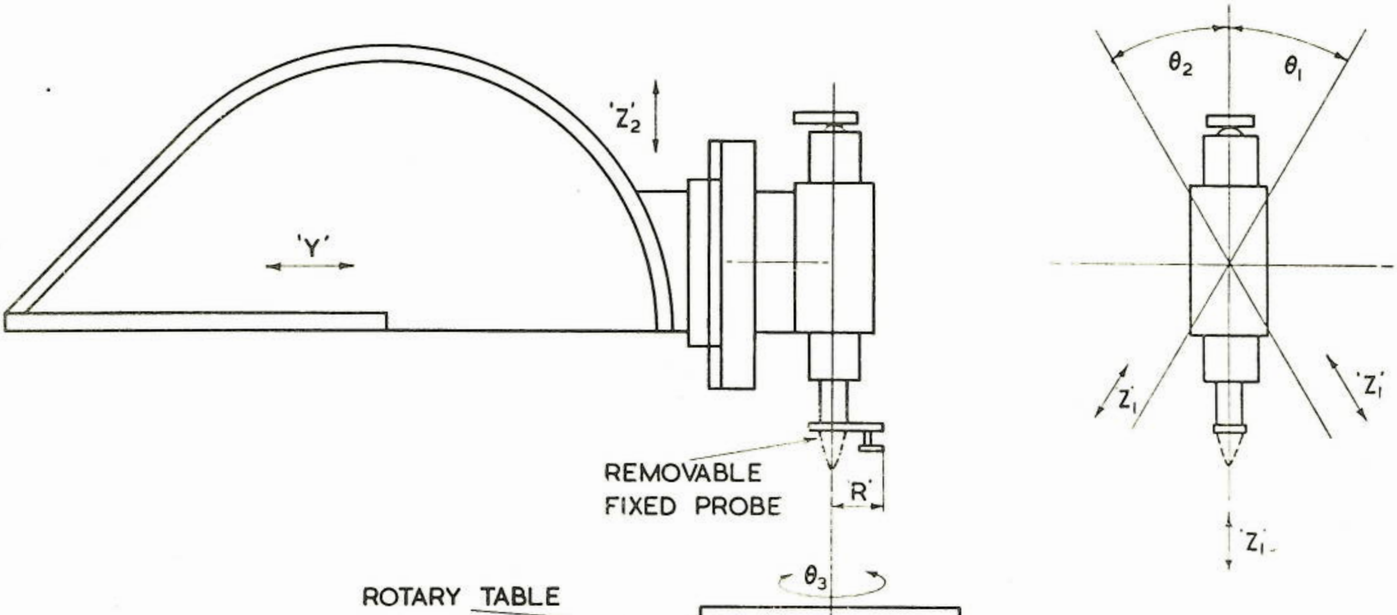
Machine No. 6

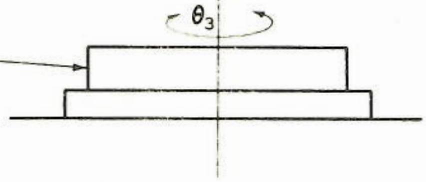
Manual adjustment on X, Y, Z_1 and Z_2 axes and angle of Z_2 axis in increments of 0°-30' through 90° clockwise and 90° anti-clockwise from vertical. Manual adjustment of radius prescribed by measuring probe and on rotation of spindle. Measurement on X_1, X_2, Y_1, Y_2, Z_1 and Z_2 axes and on radius R_1, R_2 and R_3 and on angle θ.



Component 6

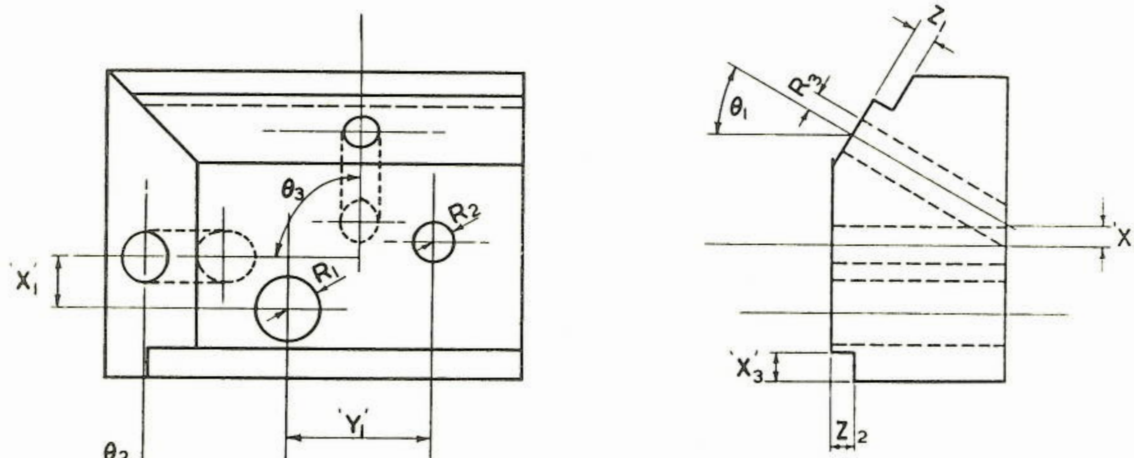
Showing measurement on X_1, X_2, Y_1, Y_2, Z_1 and Z_2 axes and on radius R_1, R_2 and R_3 and on angle θ.

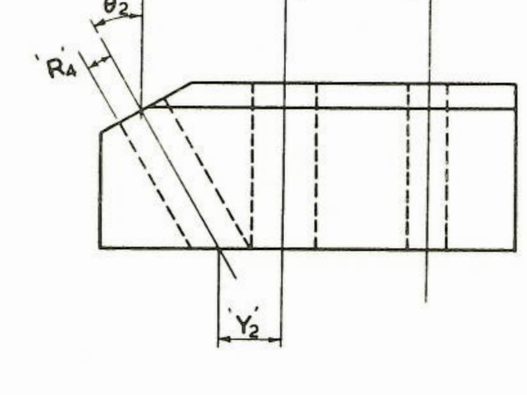




Machine No. 7

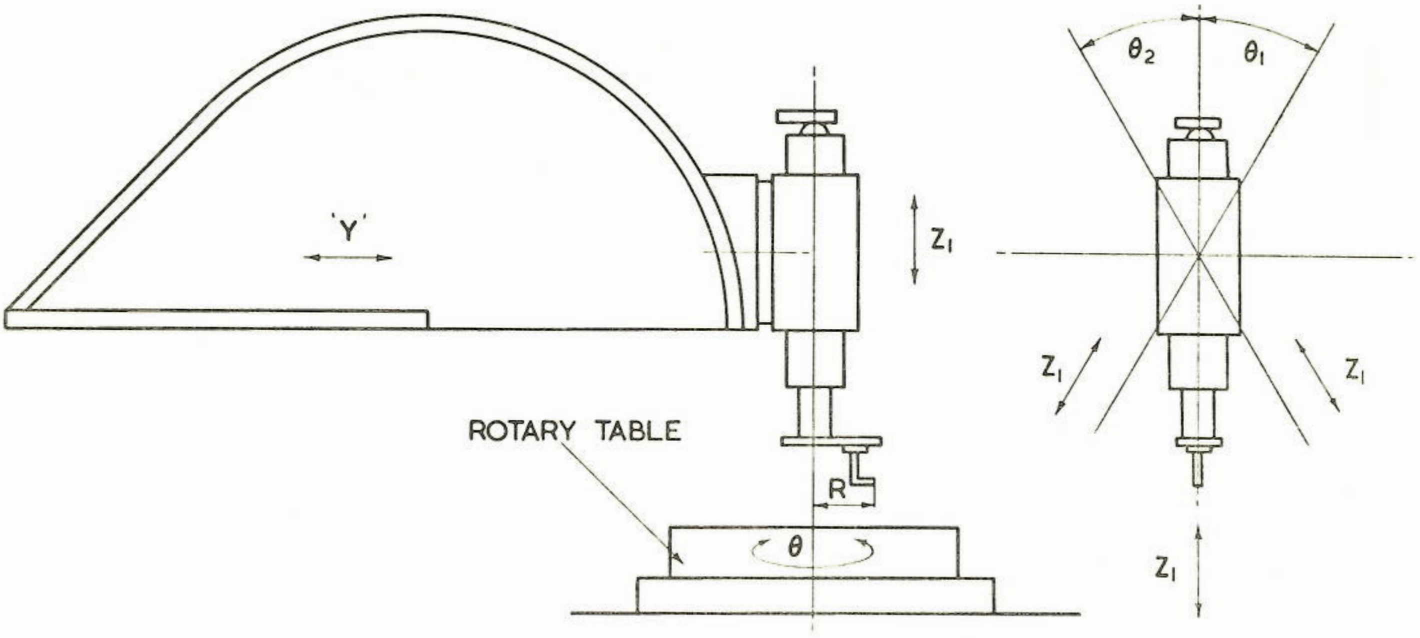
Manual adjustment on X, Y, Z_1 and Z_2 axes and angle of Z_2 axis in increments of 0° - 30' through 90° clockwise and 90° anti-clockwise from vertical. Manual adjustment of radius prescribed by measuring probe and on rotation of spindle and rotation of table. Measurement on X_1, X_2, Y_1, Y_2, Z_1 and Z_2 axes and on radius R_1, R_2, R_3 & R_4 AND ON ANGLES θ_1, θ_2 and θ_3





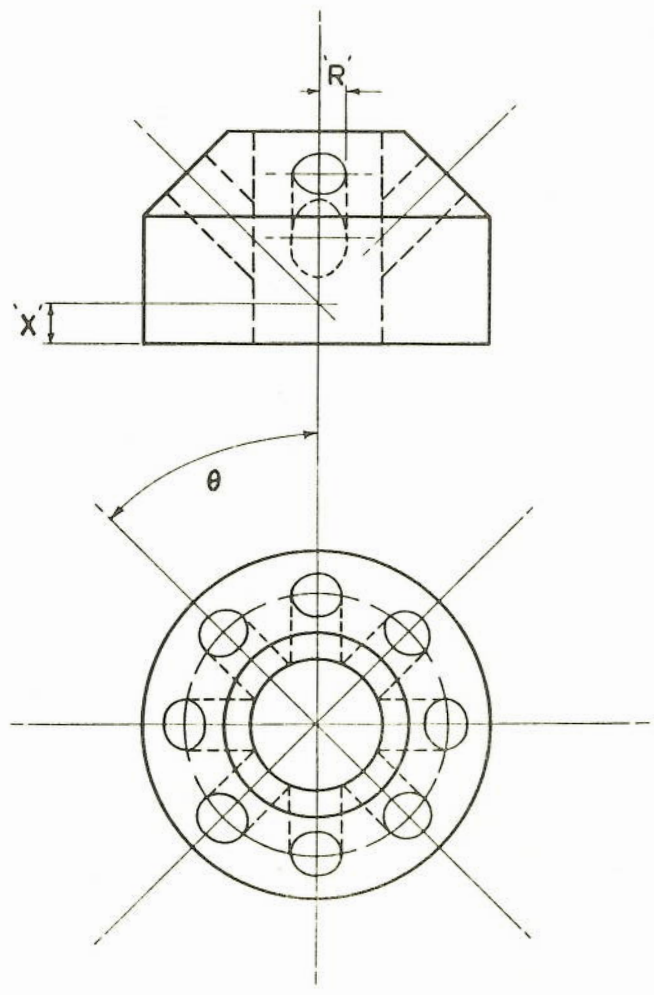
Component 7

Showing measurement on X_1, X_2, X_3, Y_1, Y_2, Z_1, Z_2 and on radius R_1, R_2, R_3 and R_4 and on angles θ_1, θ_2 and θ_3.



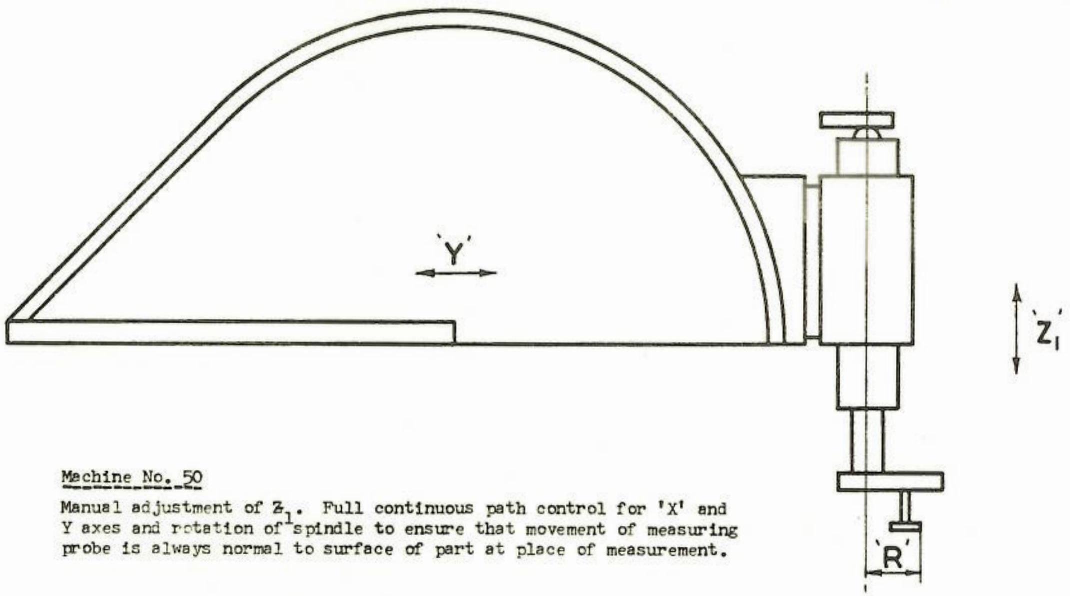
Machine No. 8

Manual adjustment on X and Y axes and on angle θ and radius R.
Point to point control for movement on Z_1 axis. Rotation of spindle and rotation of circular table. Measurement on R and θ.



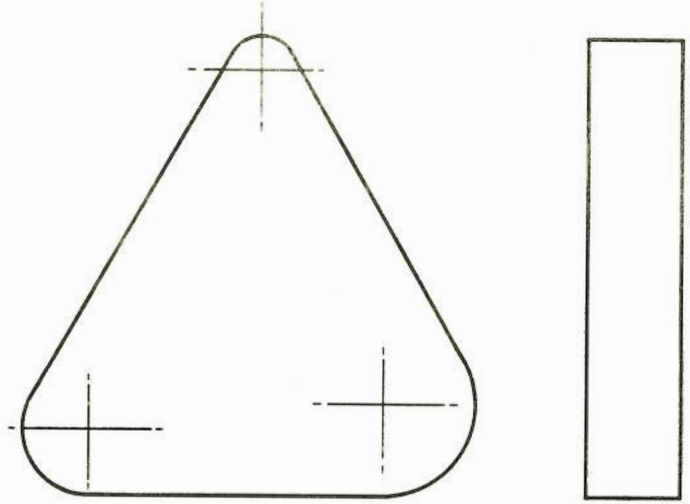
Component 8

Showing measurement of 'X' and 'R'



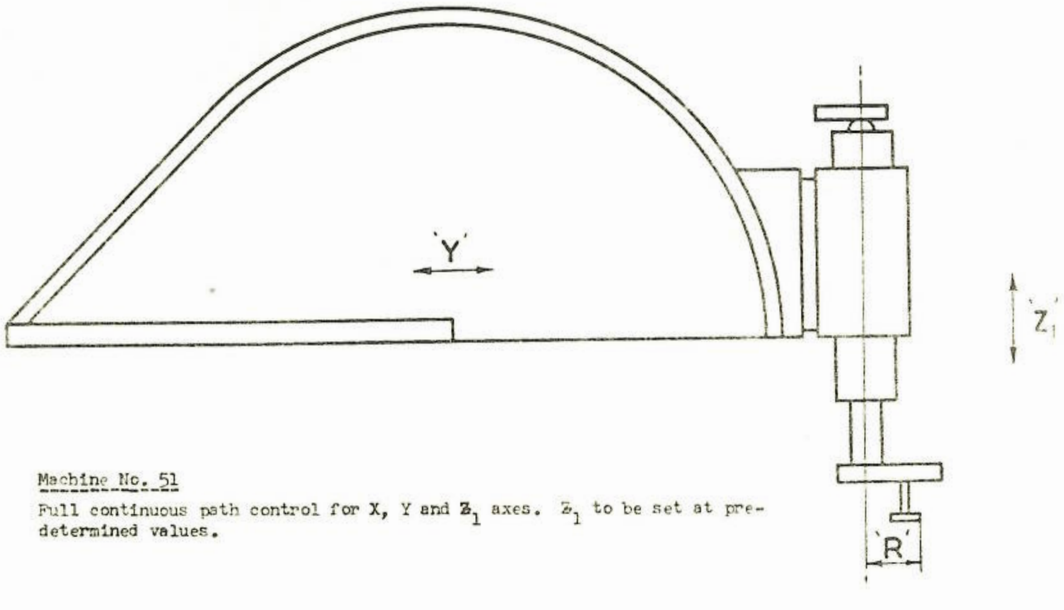
Machine No. 50

Manual adjustment of Z_1. Full continuous path control for 'X' and Y axes and rotation of spindle to ensure that movement of measuring probe is always normal to surface of part at place of measurement.



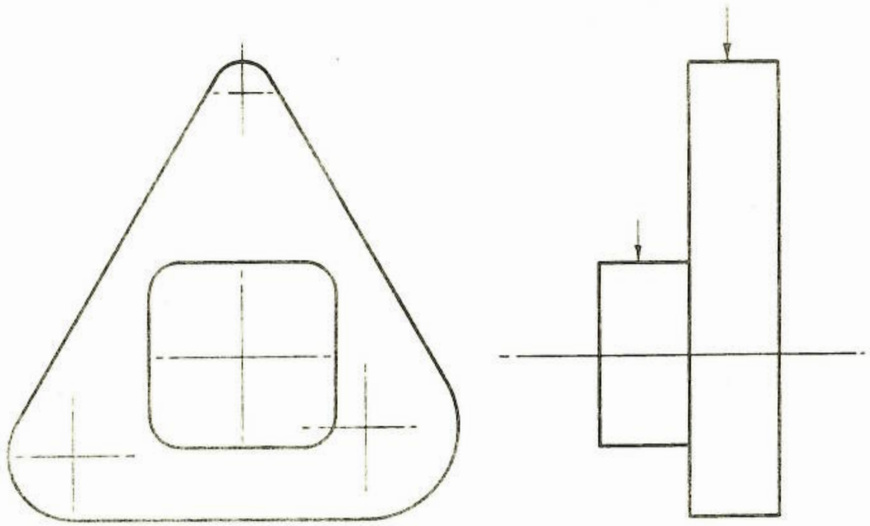
Component No. 50

Measurement of triangular shaped external surface.



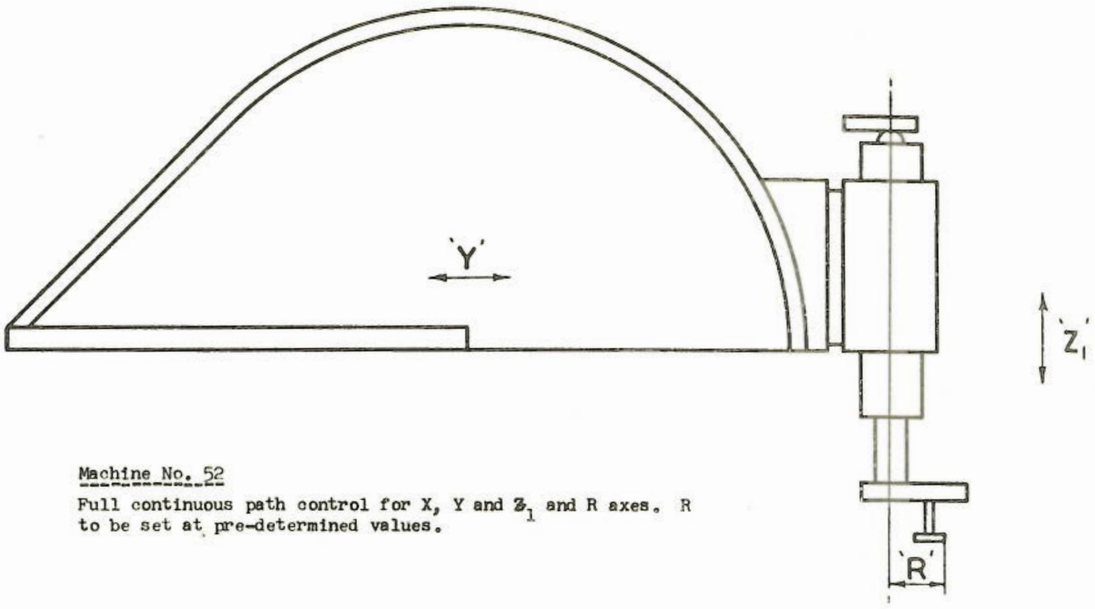
Machine No. 51

Full continuous path control for X, Y and Z_1 axes. Z_1 to be set at pre-determined values.



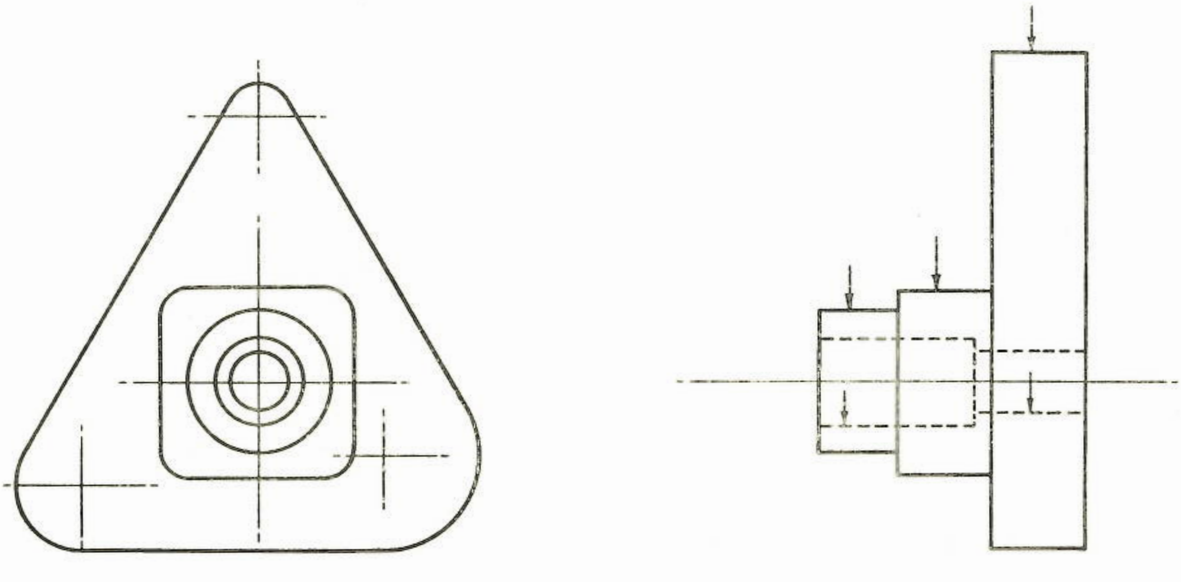
Component No. 51

Measurement of triangular and rectangular shaped profiles.



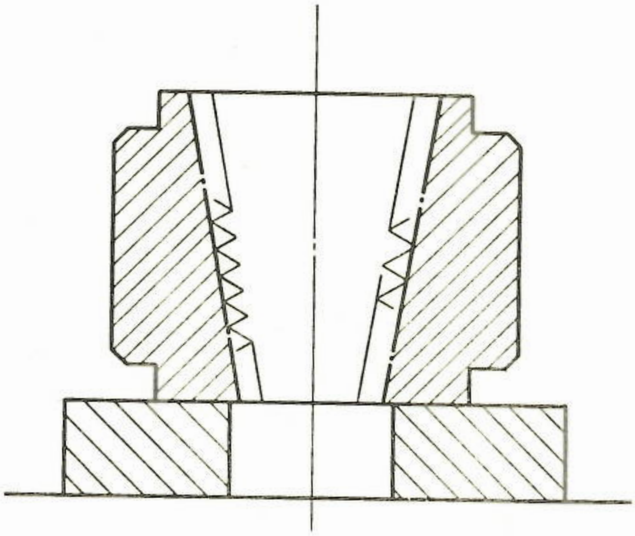
Machine No. 52

Full continuous path control for X, Y and Z_1 and R axes. R to be set at pre-determined values.



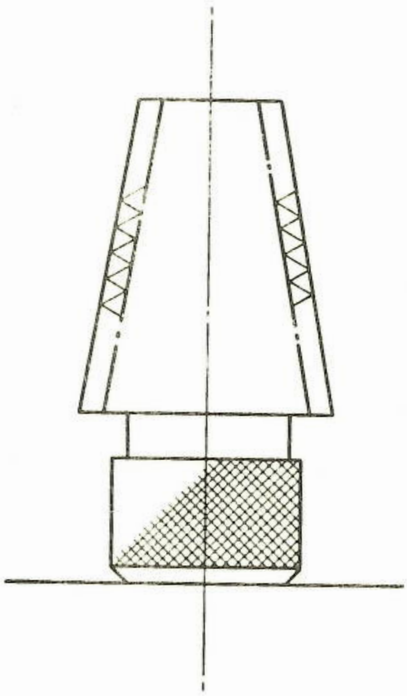
Component No. 52

Measurement of circular, triangular and rectangular shaped external profiles and position and cylindricity (in contrast to circularity) of two concentric circular holes.



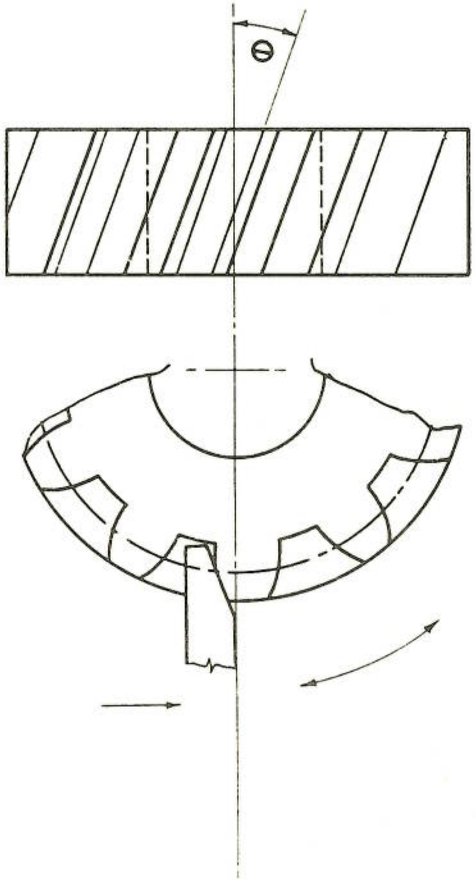
Component No. 57

Showing measurement of radius and pitch on an internal taper thread gauge.



Component No. 58

Showing measurement of radius and pitch on an external taper thread gauge.



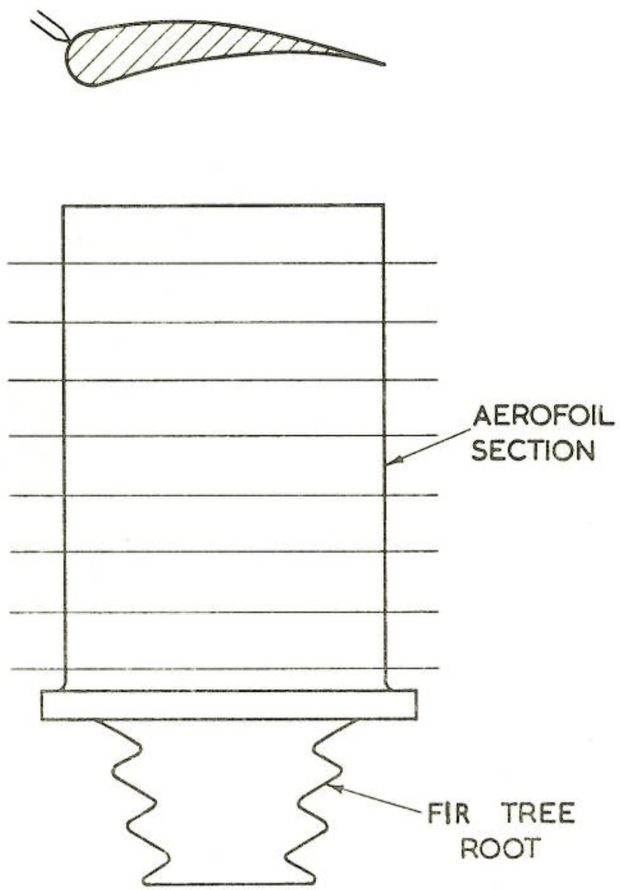
Component No. 59

Showing measurement of spiral gear :-

1. Spiral gauge
2. Circular pitch
3. Pitch circle radius
4. Involute profile.

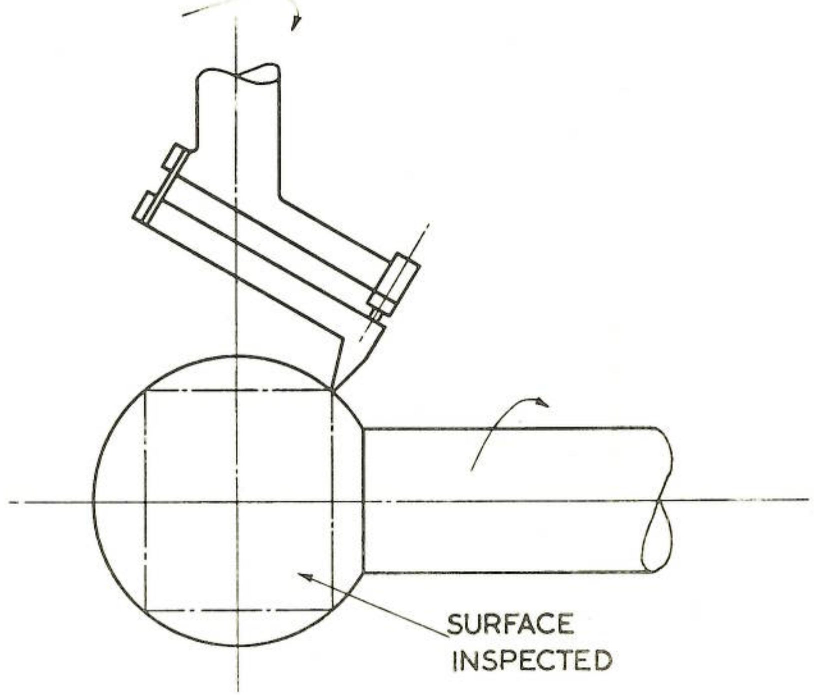
Also as before for :-

1. Spur Gear
2. Internal Gear
3. Bevel gear
4. Spiral bevel gear



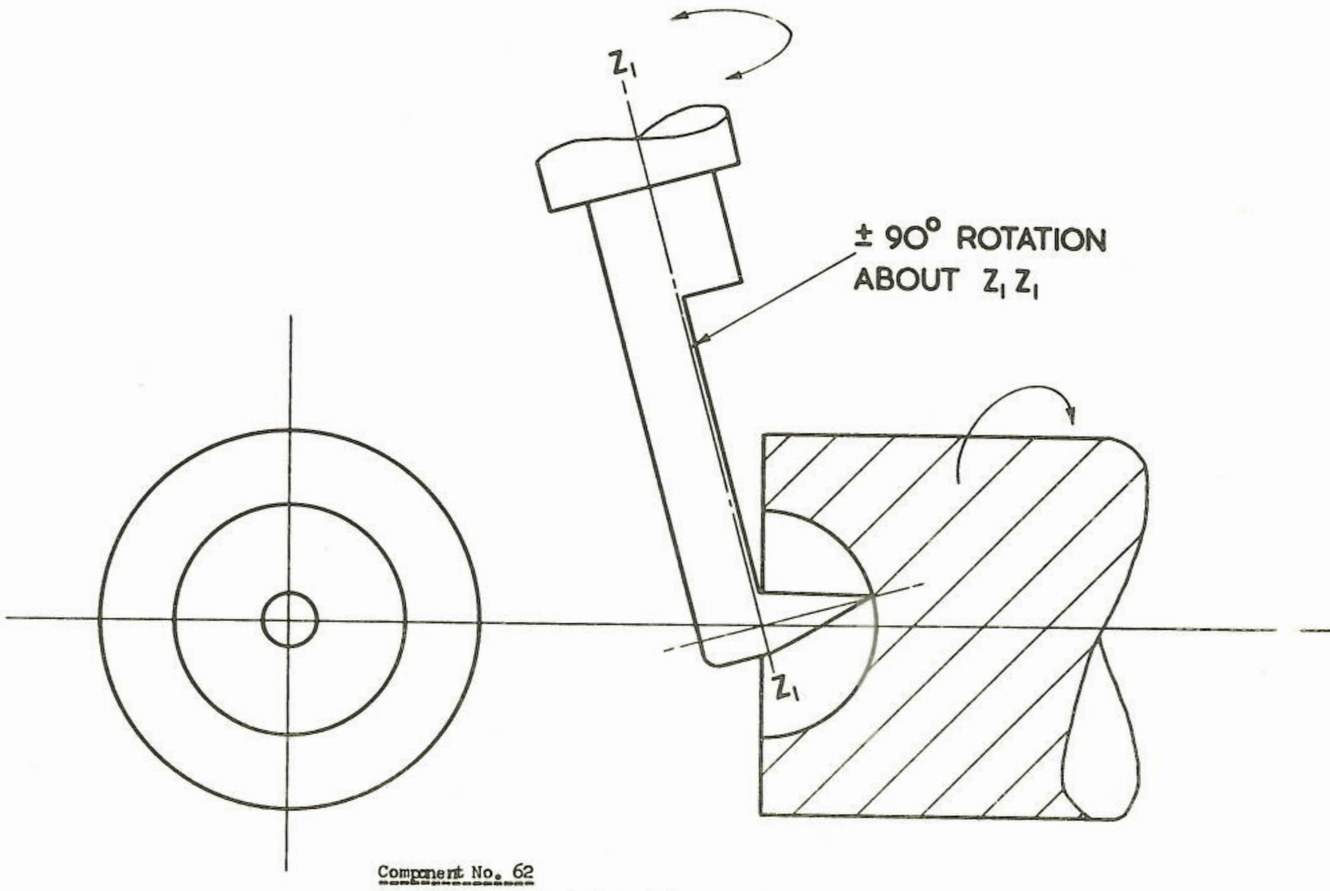
Component No. 60

Profile measurement of an aerofoil section and fir tree root.



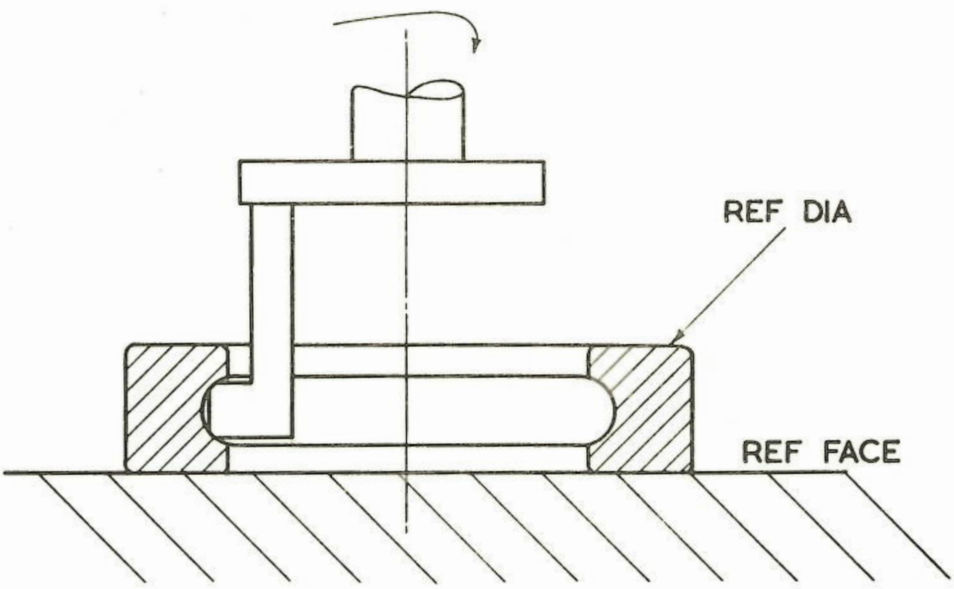
Component No. 61

Profile measurement of an external spherical shape.



Component No. 62

Profile measurement of an internal spherical shape.



Component 63

Showing measurement of bearing outer race :

Inspect for :-

radius of track
Eccentricity of track
wobble of track