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(71) Applicant (*for all designated States except US*): **RENISHAW PLC** [GB/GB]; New Mills, Wotton-under-edge Gloucestershire GL12 8JR (GB).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **PICKETT, David, George** [GB/GB]; 3 Hayesley Cottages, Church Road, Windsor Edge, Nailsworth Gloucestershire GL6 0NR (GB). **BUCKLAND, Stefen, Keith** [GB/GB]; 8 Deridene Court, Totton, Southampton Hampshire SO40 8WS (GB).

(74) Agents: **ROLFE, Edward, William** et al.; Renishaw Plc, Patent Department, New Mills, New Mills, Wotton-under-edge Gloucestershire GL12 8JR (GB).

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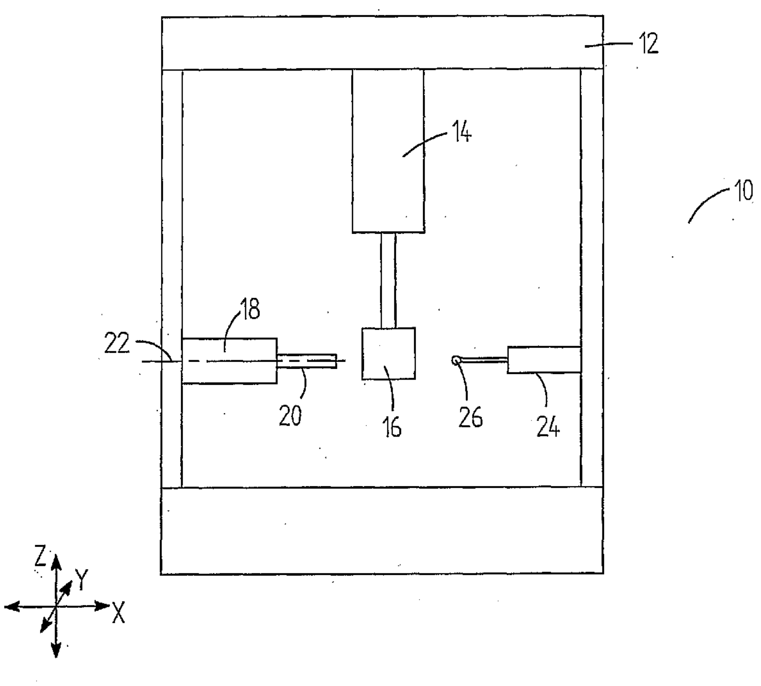
(54) **Title:** METHOD OF MACHINING A PART



(57) **Abstract:** A method of machining a part from a blank, comprising the steps of cutting an assessment tool cut in the blank using a tool, assessing the assessment tool cut, determining a difference between a nominal tool cut and the actual assessment tool cut and performing a part forming cutting operation on the blank using the tool. The step of performing the part forming cutting operation includes compensating for any difference determined.

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METHOD OF MACHINING A PART

This invention relates to a method of machining a part.

When a cutting tool is used for drilling or milling features, it suffers wear and perhaps breakage. The effectiveness of a cutting tool in a milling procedure can be assessed in a number of different ways. One way is to check the tool itself by monitoring tool vibration, rotational speed or, visually inspecting the tool using a sensor or tool setter.

Alternatively the lifetime of a tool, for particular milling conditions, can be estimated by doing a series of milling processes or wear tests. A tool can either be changed before it wears to a significant degree or tends to break based on the wear information. Alternatively, its effectiveness can be checked when it reaches a certain age.

Rather than checking the tool, when the machining process is a repetitive process, the machined product can be monitored. For example, as described in Published International Patent Application WO93/07445, the punching of holes in sheet material is monitored by optically or mechanically probing the punched holes. When the tool becomes dull or broken, the holes punched will no longer be consistently of the required diameter and the process can be stopped and the tool changed. This is a pass / fail system.

According to a first aspect of the invention, there is provided a method of machining a part from a blank, comprising the steps of: (i) cutting an assessment tool cut in the blank using a tool; (ii) assessing the assessment tool cut; (iii) determining a difference between a nominal tool cut and the actual assessment tool cut; and (iv) performing a part forming cutting operation on the blank using the tool, in which step (iv) includes compensating for any difference determined in step (iii) between the nominal tool cut and the actual assessment tool cut.

Such a difference in tool cut can be caused by a change in the effectiveness of the tool i.e. due to damage of the cutting surface or, a difference between the nominal tool size and shape and the actual tool size and shape. It could also be caused by judder, for example caused by drag.

Using the method of the invention it is possible to machine a part from a blank to a high degree of accuracy. Any change in the effectiveness of the tool is determined prior to the step of cutting the blank to form the part, and so appropriate compensation can be made during the cutting of the part to ensure that the part is machined as desired. This has been found to be less wasteful then determining the accuracy of a feature of a part once it has been cut and then discarding the part if the cut is not within a predetermined tolerance.

It has also been found that performing the assessment tool cut on the blank from which the part is machined results in a more accurate part being formed.

An assessment tool cut can be a feature cut in the blank which does not form a part of the shape of the machined part. A part forming cutting operation can be a process of removing material from the blank in order to form the shape of the machined part.

Accordingly, there is described herein a method of assessing tool performance comprising the steps of: assessing a feature cut by the tool; and compensating for any difference between a nominal tool cut and the actual tool cut.

The invention is particularly applicable to machining centres which use fixed tools as in these circumstances the tool cannot be moved to a tool checker or sensor for assessment.

The invention is also applicable where coated tools are used, i.e. the tool comprises a shank which is coated, an example is a diamond bur coating, to effect the milling process. Such tools have a nominal diameter but this will vary slightly from tool to tool, with erosion through use, or when loose diamonds are removed from the tool surface. Such tools are cheaper than accurately manufactured tools but must be set i.e. the actual cut of the tool must be established in order that accurate machining processes can be carried out with the tools.

As the actual cut of a tool is being assessed, the tool itself can be flexible and allowed to deform i.e. bend during the milling process as such distortion can be compensated for. This means that the milling of hard materials such as sintered ceramic materials is facilitated. When such hard materials are being machined, even expensive, stiff tools will flex, making a tool cut unpredictable unless an assessment cut is machined, measured and used to compensate for any flexing by manipulation of the subsequent milling process. Various compensations or offsets to account for the information gained by carrying out the assessment cut are input into the machining program resulting in alteration of the path that the tool takes whilst carrying out the machining program.

Once a feature which has been milled by a tool has been assessed, the actual cut is compared to the expected cut so the real location of the tool cutting surface with respect to a workpiece is established. Any difference between the expected and actual cut is compensated for in a subsequent milling process.

The part can be a dental prosthesis. For instance, the part can be a dental coping. Optionally, the part can be a dental bridge.

The assessment feature can be assessed by a contact measurement probe.

Step (i) can comprise cutting a plurality of assessment tool cuts. Step (ii) can comprise assessing each of the assessment tool cuts. Step (iii) can comprise determining a difference between a nominal tool cut and the actual assessment tool cut for each of the assessment tool cuts. This is advantageous as it enables different properties of the tool and the cuts it makes to be determined and for any differences to be compensated for in step (iv).

Preferably, step (i) comprises cutting an assessment tool cut which enables the length of the tool to be determined. Preferably, step (i) comprises cutting an assessment tool cut which enables the diameter of the tool to be determined. For instance, step (i) could comprise cutting a flat feature into the blank. Preferably, step (i) comprises cutting an assessment tool cut which enables more than one property of the tool to be determined. For instance, step (i) could comprise cutting an assessment tool cut which enables the length and diameter of the tool to be determined. Accordingly, in this case step (iii) can comprise determining a difference between a nominal tool cut and the actual assessment tool cut for more than one dimensional property of the assessment tool cut.

Preferably, step (i) comprises cutting an assessment tool cut which enables the tool tip radius to be determined. For instance, step (i) could comprise forming a bore in the blank using the tool. Optionally, step (i) could comprise cutting a curved feature in the blank using the tool tip. For instance, step (i) could comprise cutting a curved chamfer feature at a corner of the blank using the tool tip.

The method can comprise performing steps (i) to (iv) a plurality of times. This enables the quality of the machining to be monitored throughout the machining process.

The method can comprise repeating steps (i) to (iv) with a second tool. This enables the part to be accurately machined using the method of the present invention using more than one tool.

Preferably, the cutting of the blank is achieved via milling the blank with a milling tool.

According to a second aspect of the invention, there is provided an apparatus for machining a part from a blank, comprising: a blank holder to which a blank from which a part is to be machined can be fixed; a tool manipulator to which a tool for cutting the blank to machine the part can be fixed; a measurement device for measuring a feature cut in the blank; and a controller configured to control the operation of the apparatus so as to machine a part in accordance with the method of the present invention.

According to a third aspect of the invention, there is provided a computer program product, which when executed by a controller for an apparatus for machining a part from a blank causes the controller to control the apparatus to perform the method of the present invention.

The invention will now be described by way of example, with reference to the accompanying drawings, of which:

Fig 1 shows a machining centre;

Figs 2a and 2b show schematically, a tool and cutting profile thereof respectively;

Fig 3 shows examples of milling processes that can be carried out to assess tool performance; and

Figs 4a and 4b show alternative methods of establishing tool tip radius.

Fig 1 shows a machining centre 10 having a gantry 12 which supports a holder 14 to which a sample 16 can be fixed. The machining centre 10 also supports a tool holder 18 to which a milling tool 20 can be attached.

The tool 20 rotates about its longitudinal axis 22 but is fixed in location with respect to the machining centre 10. The sample 16 can be moved within the working volume of the machining centre 10 in x, y and z axes enabling different parts of an aspect of the sample to be presented to the tool. In order that other aspects of the sample can be presented to the tool, the sample can be removed, manually rotated and re-inserted into the holder 14, or the holder 14 can be provided with a motor enabling rotation thereof.

The tool holder 18 is shown with its longitudinal axis 22 transverse to that of the sample holder, however, it could be disposed essentially parallel to the sample holder or, other tool holders can be located about the machining centre 10 enabling different tools to be used in the milling process without the need to stop the process to change a tool.

A probe 24 is also provided within the working volume of the machining centre 10. In this example, the probe 24 is a contact probe and has a workpiece contacting tip 26 which deflects on contact with a surface of the sample 16. Alternatively, a non-contact (for example an optical) probe can be provided.

Fig 2a shows a tool 20 with a diamond bur coating 30. The coating 30 is not uniform, but gives a nominal tool profile 32 which indicates what the diameter of a cut by this type of tool should be. As the tool coating process is not repeatable and as diamond burs will break off the tool during use, this nominal profile is indicative only and will change over time.

A diamond bur coating can be formed on a tool shank in a number of ways for example, by sintering a mixture of diamond powder and metal (which can include bronze) onto the shank or, by placing a shank which has diamond powder packed around it into a nickel plating tank and plating the powder onto the shank.

Fig 2b shows a desired or expected cut profile 32 and an actual cut profile 34. The difference between the two lines is due to the variation in the cutting surface of the tool, wear of the cutting surface, bending of the tool during the cutting process and inaccuracies in sample to tool positioning (if the machine has not been calibrated).

The actual cut 34 is measured, preferably by using a contact or non-contact probing system and differences from the expected cut are compensated for in the positioning of the sample with respect to the tool. If the same cut is made using the tool compensation that has been calculated for that tool, the actual cut profile 36 follows the expected cut profile 32 closely.

Fig 3 shows a set of tool assessment cuts which can be carried out on a component blank or sample from which a part is to be machined, to provide compensation information for tool. The blank 40 is provided of sufficient size to allow the assessment cuts to be carried out on it as this produces more accurate results than using a separate assessment blank particularly in situations where the material being machined has variable properties such as density which affects wear and the degree of bend of the tool during machining.

Firstly, the position of the blank 40 is located using the probe 24 (see Fig 1). One way to achieve this is to establish the centre of the blank by taking at least four separate measurements with the probe around the outside of the blank. If the blank is a cube, perhaps at least one measurement per side in a plane. It is advantageous to take all the measurements in one plane as then two of the dimensions of the blank are easily established during this process. The centre of the blank is compared to the centre of rotation or centre line of the holder 14 (see Fig 1) and any differences noted and compensation is used to account for said difference. This data along with approximate tool dimensions then gives an approximate relative location of the tool to the blank which is used to establish exact relative locations using the tool assessment process.

In this example three different cuts 42,44,46 are carried out, one to establish the location of the end of the tool, one for tool diameter and one for tool tip radius respectively.

The location of the tool tip is established by machining a flat 42 into one of the faces of the blank 40. The depth 42b of the flat 42 is measured by the probe and if it is within tolerance, say 10μm from the instructed cut depth, then no compensation is required. However, if the difference is too great, a tool length offset is calculated, stored and used for future machining processes with that tool.

The diameter of the tool is established by machining a flat 44 into one of the surfaces of the blank 40. The depth 44a is measured by the probe and if it is out of tolerance then a tool diameter offset is calculated, stored and used for future machining processes with that tool.

It is possible, if a reasonably accurate positioning of the tool is achieved, to obtain data regarding the tool length and diameter from the length cut 42 as the width of this cut 42a could indicate the tool diameter. Alternatively, the diameter cut 44 may be used to give both diameter and length data for the tool as the depth of cut 44b could indicate the tool length if, accurate tool positioning for the cut is achieved.

The tool tip radius is established by cutting a radial feature 46 into the blank and measuring this with the probe. The resultant data is fitted into a circular form from which the tip radius is calculated.

If there are more tools the tool setting procedure outlined above can be repeated for the other tools. For example the method for machining the part from the blank might utilise a roughing cutter and a finishing cutter. Accordingly, the tool setting procedure can be used for both of these cutters.

Furthermore, the tool setting procedure outlined above can be repeated for the same tool multiple times, for instance at certain intervals. For instance, the tool setting procedure can be performed on a tool prior to and/or subsequent every machine cutting operation which is performed by the tool to form the part from the blank 40. Furthermore, in this case tool setting data obtained subsequent to a machine cutting operation can be compared with tool setting data obtained prior to a machine cutting operation in order to obtain an indication of the quality of the cut obtained from the machine cutting operation.

In an alternative embodiment, the tool setting data is acquired by drilling a hole 52 (Fig 3) into the blank. The depth and diameter are measured to give tool length and diameter respectively. The tool tip radius can be established in a number of ways.

Referring now to Fig 4a, if the tool tip radius R_1 is larger than the probe tip radius 26a then the tool tip radius can be measured directly using the drilled hole as the bottom of the hole replicates the profile of the tool tip.

If the tool tip radius R_1 is smaller than the probe tip radius 16b as shown in Fig 4b then, one can machine out from the drilled hole 52 in an arc of radius R_2 which is greater than the radius R_1 of the probe tip 26. The tool tip radius R_1 can be established via a simple calculation based on the resultant hole radius R.

Once the tool setting procedure for a tool has been completed, a cutting operation on the blank 40 can be performed to form the part using the tool. For instance, a dental part, such as a coping can be formed by milling the blank 40 according to a predetermined milling operation. An accurate cut can be obtained during the milling operation by compensating for any differences determined during the tool setting procedure.

When the material being machined is particularly hard, such as sintered ceramic, it is preferred that the tool is assessed during the stages of the machining process as wear during the machining process affects the cut of the tool tip. This then allows for the machining program to be amended to reflect any changes in the cutting region of the tool thus ensuring accurate machining of the part.

Any compensation that is required in order to change the tool cut from its actual cut to the desired or nominal cut, can be applied to a milling or cutting program. This cutting software is located in a machine controller, interface or computer which, in use is in communication with the machining centre.

Claims

1. A method of machining a part from a blank, comprising the steps of:

(i) cutting an assessment tool cut in the blank using a tool;

(ii) assessing the assessment tool cut;

(iii) determining a difference between a nominal tool cut and the actual assessment tool cut; and

(iv) performing a part forming cutting operation on the blank using the tool,

in which step (iv) includes compensating for any difference determined in step (iii).

2. A method according to claim 1 wherein, the tool comprises a shank which is coated.

3. A method according to any preceding claim wherein, the tool is flexible.

4. A method according to any preceding claim wherein, the blank comprises a hard material.

5. A method according to claim 4 wherein, the hard material is a ceramic material.

6. A method according to any preceding claim wherein, the compensation is made by modifying a tool cutting path.

7. A method according to any preceding claim wherein, various compensations or offsets to account for the information gained by carrying out the

assessment cut are input into a machining program resulting in alteration of the path that the tool takes whilst carrying out the machining program.

8. A method according to any preceding claim wherein the step of assessing the assessment tool cut by the tool comprises measuring the cut using a measurement probe.

9. A method according to any preceding claim wherein, the part is a dental prosthesis.

10. A method according to any preceding claim wherein the method comprises performing steps (i) to (iv) a plurality of times to machine the part.

11. A method according to any preceding claim wherein, the method further comprises repeating steps (i) to (iv) using a second tool.

12. A method according to any preceding claim in which step (i) and/or (iv) comprises milling the blank with a milling tool.

13. An apparatus for machining a part from a blank, comprising:

a blank holder to which a blank from which a part is to be machined can be fixed;

a tool manipulator to which a tool for cutting the blank to machine the part can be fixed;

a measurement device for measuring a feature cut in the blank; and

a controller configured to control the operation of the apparatus so as to machine a part in accordance with a method as claimed in any of the preceding claims.

14. A computer program product, which when executed by a controller for an apparatus for machining a part from a blank causes the controller to control the apparatus to perform the method as claimed in any of claims 1 to 12.

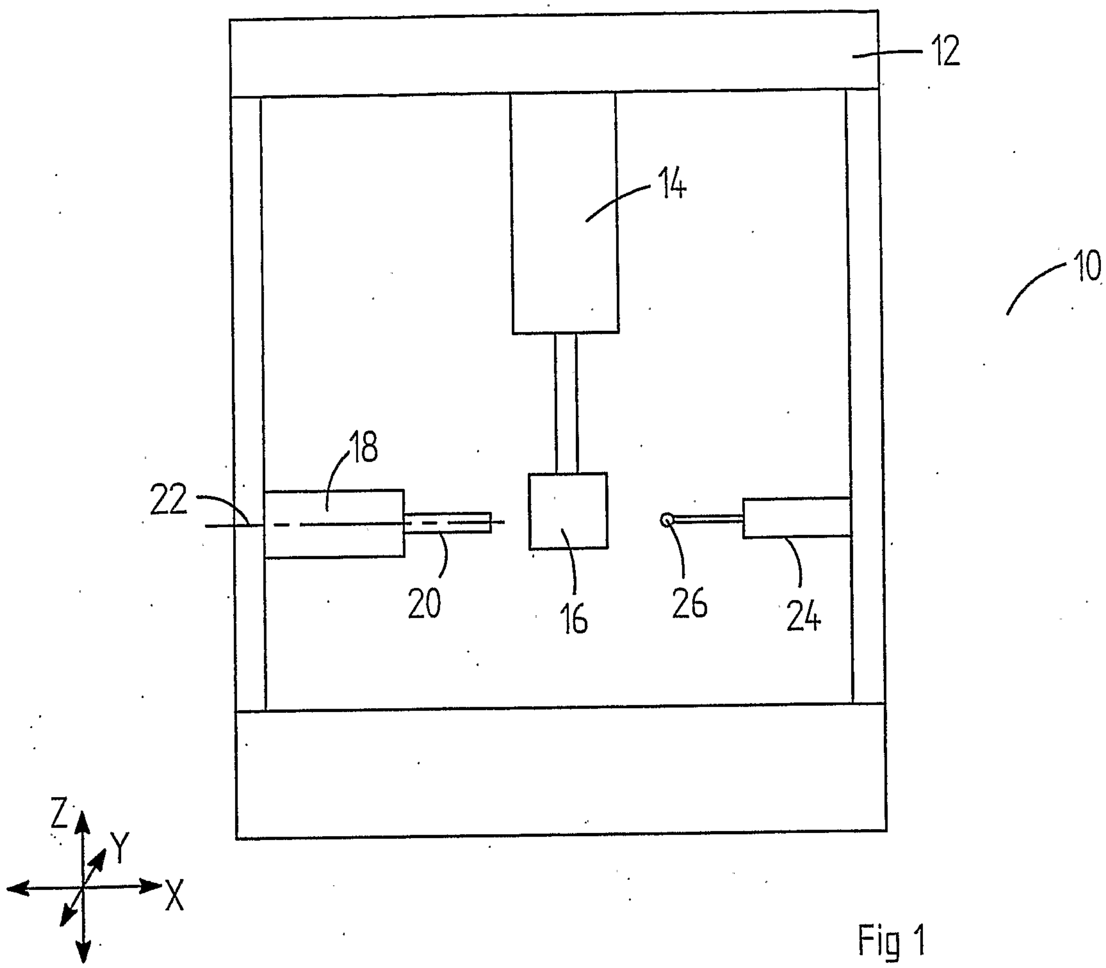

Fig 1

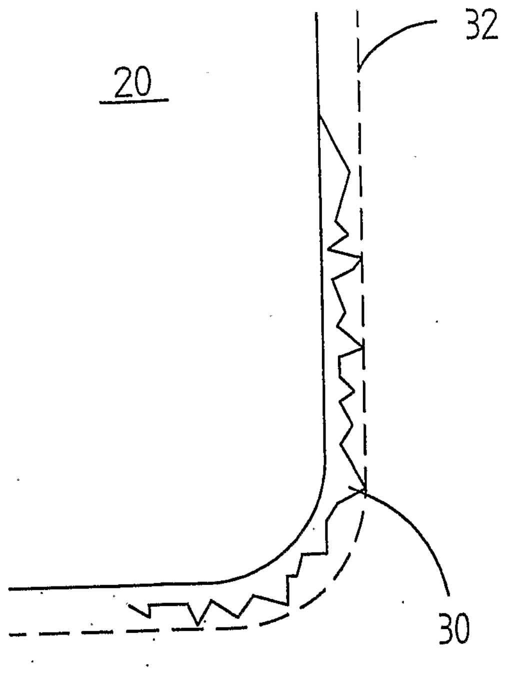

Fig 2a

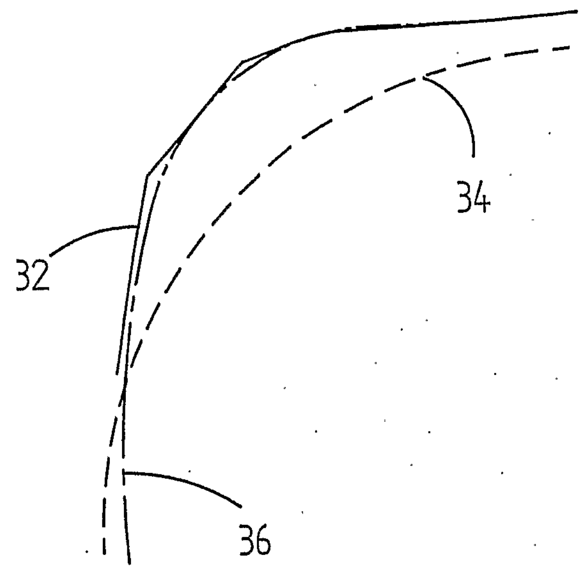

Fig 2b

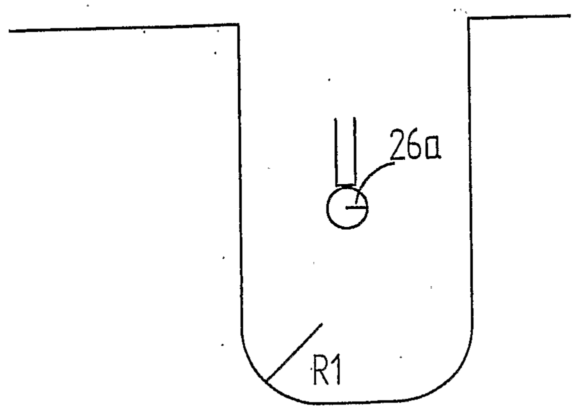

Fig 4a

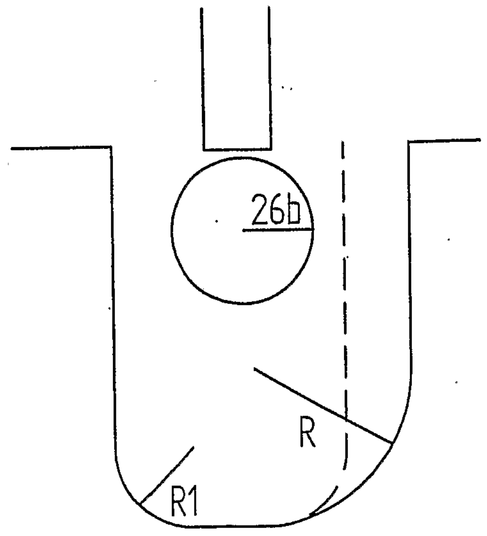

Fig 4b

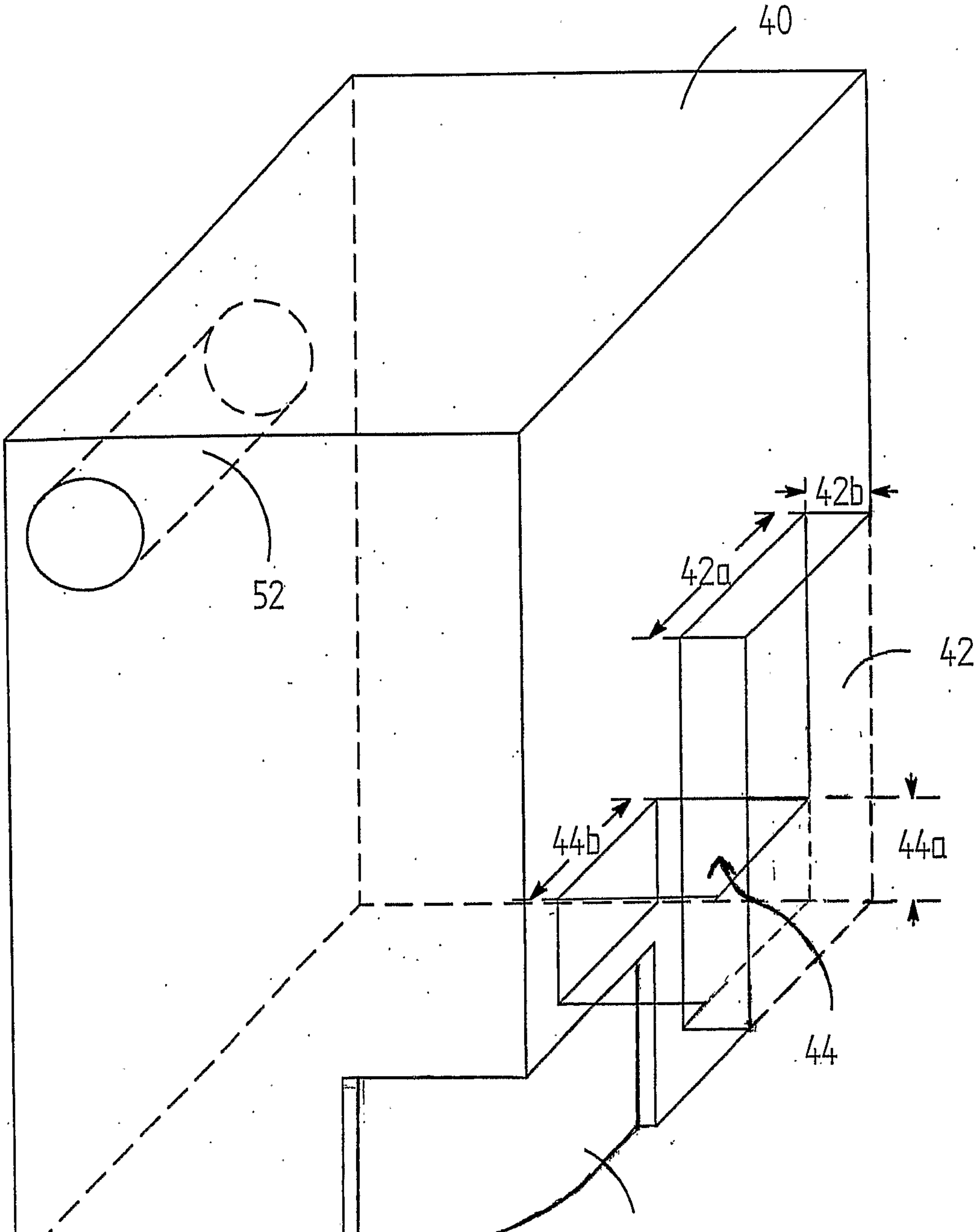

Fig 3