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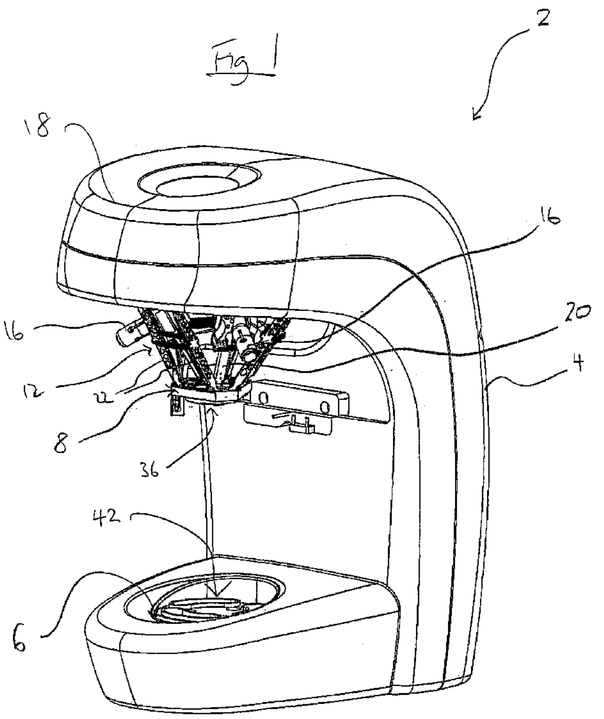

(57) Abstract: This invention relates to a machine structure apparatus for scanning and machining objects. The machine structure comprises a base and a platform moveable relative to the base. The base has first kinematic mount formations and the platform has second kinematic mount formations such that an object support, a tool holder for holding and actuating a workpiece shaping tool and a measurement probe can be mounted on at least one of the first and second kinematic mount formations via corresponding kinematic mount formations. Accordingly, the machine structure can be used as a scanning machine or as a machine tool.

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MODULAR SCANNING AND MACHINING APPARATUS

This invention relates to a modular scanning and machining apparatus, and particularly but not exclusively to such apparatus for scanning and machining small parts, for instance dental parts.

Parts, for instance models of teeth, can be measured accurately by scanning the part using a coordinate positioning apparatus, for instance a non-cartesian measuring apparatus such as a parallel kinematic system, or cartesian measuring apparatus such as a coordinate measuring machine (CMM). For example, a contact or non-contact probe can be scanned across the surface of the part by a coordinate positioning apparatus in order to obtain precise measurement data. It is known to provide probes in a modular configuration such that different stylus modules and styli can be mounted via kinematic mounts onto a probe body that is fixed to the coordinate positioning apparatus. It is also known to mount a part for inspection to the coordinate positioning apparatus via a kinematic mount, for instance as described in published patent application no. WO 03/062740.

Once sufficient measurement data of the part has been obtained, a replica part or other type of part can be machined using the measurement data. This can be performed on a CNC machine tool which uses the measurement data to control the driving of a tool, such as a drilling, milling or grinding tool, into a workpiece in order to form the machined part.

The present invention provides a modular apparatus in which scanning and machining parts can be interchanged with repeatable positioning such that the apparatus can easily be swapped between being used as a scanning machine and as a machine tool.

Accordingly, in a first aspect, the invention provides a machine structure apparatus for scanning and machining parts, the machine structure comprising a base and a platform moveable relative to the base, the base having first kinematic mount formations and the platform having second kinematic mount formations. An object support, a tool holder for holding and actuating a workpiece shaping tool and a measurement probe can preferably be mounted interchangeably on at least one of the first and second kinematic mount formations via corresponding kinematic mount formations, such that the machine structure can be used as a scanning machine or as a machine tool.

It is an advantage of the invention that the same machine structure can be used for both scanning and machining parts. The use of kinematic mount formations ensures that the positioning of the scanning and machining parts when loaded onto the machine structure is sufficiently repeatable so as to avoid having to recalibrate and/or reset the various parts each time they are loaded onto the machine structure. The use of kinematic mounts also provides for easy replacement of parts, and therefore facilitates easy upgrading and repairing of the parts used on the machine structure, and for changing the use of the machine structure.

As will be understood, the first and the second kinematic mount formations could be suitable for receiving any of an object support, measurement probe and tool holder. Preferably, the first kinematic mount formations are at least suitable for the interchangeable mounting of an object support and a tool holder for holding and actuating a workpiece shaping tool. Preferably, the second kinematic mount formations are at least suitable for the interchangeable mounting of an object support and a measurement probe.

As will be understood a kinematic mount is one which has elements on one part which are arranged to cooperate with elements on another part to provide highly repeatable positioning. The elements are arranged to cooperate with each other so as to constrain relative movement between the parts in all six degrees of freedom (i.e. three perpendicular linear degrees of freedom and three perpendicular rotational degrees of freedom) preferably by six points of contact or constraints.

Although not necessary, the six points of contact can all be in the same plane.

In one particular embodiment, the elements on one of the parts can be arranged to provide a pair of mutually converging surfaces at each of three spaced locations, in such a manner as to provide a total of six points of contact with the elements on the other part. This constrains the six possible degrees of freedom of one part relative to the other. Such a kinematic mount is sometimes known as a Boys support, and is described in, for example, H. J. J. Braddick, "Mechanical Design of Laboratory Apparatus", Chapman & Hall, London, 1960, pages 11-30. Braddick also describes a functionally equivalent kinematic mount, sometimes known as a Kelvin support, in which the six points of contact or constraints are provided three at a first location, two at a second spaced location, and one at a third spaced location. The terms "kinematic", "kinematically constrained" and like terms, as used in this specification, encompass Boys supports, Kelvin supports and other kinematic and semi- or quasi-kinematic types of support.

Preferably the base comprises at least one first retainer portion for retaining a part, such as a measurement probe, object support or tool holder against the base. The at least one first retainer portion could be a mechanical coupling. For instance coupling could comprise a cam and puller arrangement. The at least one first retainer portion can comprise at least one first magnet for attracting a corresponding magnet in a measurement probe, object support or tool holder when mounted on the base.

Preferably, the platform comprises at least one second retainer portion for retaining a part, such as a measurement probe, object support or tool holder against the platform. The at least one second retainer portion could be a mechanical coupling. For instance coupling could comprise a cam and puller arrangement. The at least one second retainer portion can comprise at least one second magnet for attracting a corresponding magnet in a measurement probe, object support or tool holder when mounted on the platform. Preferably, the second retainer portion is sufficiently strong so as to be able to retain a part, such as a measurement probe, object support or tool holder, having a weight of at least 80 grams, more preferably at least 1000 grams, especially preferably at least 2000 grams.

Preferably, the connectors and kinematic mount formations on the base and platform are configured such that a part, such as a measurement probe, object support or tool holder is sufficiently rigidly held when mounted on the base or platform such that the breakout torque (i.e. the torque at which the part begins to decouple from the base or platform) is at least 35 Ncm, more preferably at least 40 Ncm, especially preferably at least 60 Ncm. Preferably, the breakout torque is not more than 180 Ncm, more preferably not more than 150 Ncm, especially preferably not more than 100 Ncm. Particularly preferred breakout torques can range between 60 Ncm and 100 Ncm, for example between 70 Ncm and 90 Ncm.

The machine structure apparatus can comprise at least one connector for electrically connecting to at least one corresponding connector on a part, for instance a measurement probe or tool holder, when mounted on the platform. The at least one connector can be a non-contact connector. For example, the connector can be a wireless connector. Optionally the connector can be an inductive connector. Furthermore, the connector could be an optical connector. The at least one connector can be a contact connector. The at least one contact connector could be a floating connector. For instance, the connector could comprise a spring pin for contact with a contact pad on the part to be mounted on the platform. Accordingly, in this case the connector will not fight against the kinematic mount formations when a part, for instance a measurement probe or a tool holder, is mounted on the platform. However, it will also be understood that this effect could be achieved by providing the floating connector on the part to be mounted on the platform, in which case the connector on the platform need not be floating.

Preferably, the platform comprises the at least one connector. Preferably, the at least one connector is disposed on the same face of the platform as the second kinematic mount formations.

The at least one connector can be a power supply connector for supplying electrical power from a power source to a measurement probe or tool holder mounted on the platform. Optionally, the at least one connector is a data connector for transferring data between a measurement probe mounted on the platform and a processing unit coupled to the data connector. Further still, at least one power supply connector and at least one data connector can be provided.

The machine structure apparatus can comprise at least one connector for electrically connecting to at least one corresponding connector on a part, for instance a measurement probe or tool holder, when mounted on the base. The at least one connector can be a non-contact connector. For example, the connector can be a wireless connector. Optionally the connector can be an inductive connector. Furthermore, the connector could be an optical connector. The at least one connector can be a contact connector. The at least one contact connector could be a floating connector. For instance, the connector could comprise a spring pin for contact with a contact pad on the part to be mounted on the base. Accordingly, in this case the connector will not fight against the kinematic mount formations when a part, for instance a measurement probe or a tool holder, is mounted on the base. However, it will also be understood that this effect could be achieved by providing the floating connector on the part to be mounted on the base, in which case the connector on the base need not be floating.

Preferably, the base comprises the at least one connector. Preferably, the at least one connector is disposed on the same face of the base as the first kinematic mount formations.

The at least one connector can be a power supply connector for supplying electrical power from a power source to a measurement probe or tool holder mounted on the base. Optionally, the at least one connector is a data connector for transferring data between a probe mounted on the base and a processing unit coupled to the data connector. Further still, at least one power supply connector and at least one data connector can be provided on the base.

Preferably, the base of the machine structure further comprises at least one conduit for fluidly connecting at least one conduit in a tool holder when mounted on the kinematic mount formations and an extraction unit connected to the at least one conduit in the base. Preferably, the at least one conduit is disposed between the kinematic mount formations. Preferably, the at least one conduit has at least one opening for fluid connection to at least one conduit in a tool holder mounted on the kinematic mount formations. Preferably, the at least one opening is provided on the same face of the base as the kinematic mount formations. Preferably, the at least one opening extends between the kinematic mount formations.

The machine structure apparatus can further comprise a probe having kinematic mount formations for cooperation with at least one of the first and second kinematic mount formations. The machine structure apparatus can further comprise a tool holder for holding an actuating a workpiece shaping tool having kinematic mount formations for cooperation with at least one of the first and second kinematic mount formations. The machine structure apparatus can also further comprise an object holder having kinematic mount formations for cooperation with at least one of the first and second kinematic mount formations.

Further details and features concerning the machine structure apparatus which are relevant and common to both the machine structure described above and to a second aspect of the invention are described below.

According to a second aspect, the present invention provides a kit of parts comprising: a machine structure having a base and a platform moveable relative to the base, the base and the platform having first and second repeatable mount formations respectively; an object support having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations; and ii) a tool holder for holding and actuating a workpiece shaping tool, the tool holder having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations.

Preferably, the kit of parts also comprises a metrological device having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations.

Optionally, the repeatability of the repeatable mount formations is to within at least the machine's measuring repeatability. Preferably, the first and second repeatable mount formations comprise at least one projection or recess. In this case, preferably, the repeatable mount formations on the metrological device, tool holder and object holder comprise at least one projection or recess for cooperation with the at least one projection or recess of the first and second repeatable mount formations.

Preferably, the repeatable mount formations are kinematic mount formations. Accordingly, preferably the repeatable mount formations are configured to provide kinematic mounts. As described above in connection with the first aspect of the invention, a kinematic mount is one which has elements on one part which are arranged to cooperate with elements on another part to provide highly repeatable positioning.

Suitable metrological devices include those for measuring the dimensions of the work-piece. For instance, such a suitable device includes a measurement probe. The measurement probe can be a contact probe. The measurement probe can be a non-contact probe. Measurement probes typically comprise a probe body which houses at least some of the sensor componentry for enabling measurement of the work-piece. Preferably, the probe body comprises repeatable mount formations for cooperation with the second repeatable mount formations. More preferably, the second repeatable mount formations are kinematic mount formations and the probe body comprises kinematic mount formations for cooperation therewith.

Contact probes normally comprise a workpiece contacting stylus. The stylus normally comprises a tip for contacting a workpiece. The stylus can be permanently attached to the probe body which has sensors for detecting deflection of the stylus. In this case the stylus could be mounted to the probe body via a repeatable mount, for instance a kinematic mount, so as to enable the use of different styli with a probe body. Optionally the stylus can be attached to the probe body via a stylus module. In this case, the probe body typically houses the sensor for detecting deflection of the stylus and the stylus module comprises a pivot mechanism for facilitating the deflection of a stylus relative to the probe body. The stylus module could be mounted to the probe body via a repeatable mount, for instance a kinematic mount. Further, the stylus could be mounted to the stylus module via a repeatable mount, for instance a kinematic mount. Accordingly, different combinations of stylus and stylus modules could be used with one probe head. Modular measurement probes are known and are for instance described in US 6772527, the entire contents of which is incorporated into this specification by this reference.

Contact probes include rigid stylus probes and stylus deflection probes. Stylus deflection probes operate by detecting the deflection of the stylus when it is driven against a workpiece. Componentry for detecting deflection of the stylus is typically housed within the probe body.

The stylus deflection probe can be a "dual state" probe in which the probe can determine when the stylus is seated or deflected. Deflection could be detected by the breakage of contacts in the probe body caused by the stylus tilting relative to the probe body. For example, such a probe is disclosed in US 4270275, the entire content of which is incorporated into this specification by this reference.

The stylus deflection probe can be an analogue probe in which the probe can determine the extent of the deflection of the stylus. The analogue stylus deflection probe can be an optical stylus deflection probe. For example, such a probe is disclosed in published International patent application no. PCT/GB00/01303 under publication no. WO 00/60310, the entire content of which is incorporated into this specification by this reference. In this case, stylus deflection can be detected by, for example, monitoring the position of a beam of light on a position sensor, the position of the light beam being dependent on the relative position of the stylus tip and the probe body. The stylus of such a probe is typically hollow along at least a part of its length. The probe body can comprise the position sensor. In this case, the light beam source can be located toward the stylus tip. Optionally, the probe body can comprise the light beam source. The stylus can comprise a reflector towards its tip.

A measurement probe can be a non-contact probe in which the probe can measure the dimensions of the workpiece without contacting the workpiece. Non-contact probes include optical probes, capacitive probe and inductive probes, such as those disclosed in US 4,750,835 and US 5,270,664, the contents of which are incorporated into this specification by these references. The sensors of non-contact probes are typically contained within the probe body.

Preferably the platform and base are arranged such that a part, such as a measurement probe, object support or tool holder are suspended from the platform when mounted on the platform and sit on the base when mounted on the base. The platform and the base can be arranged substantially opposite to each other. For example, the platform and the base could have substantially planar faces on which the repeatable mount formations are provided and the platform and the base could be configured such that the planar faces face each other. The planar faces could be held in a substantially parallel and spaced apart relationship. The platform and the base can be arranged such that one is generally above the other. For instance, the platform could be arranged to be substantially above and substantially opposite the base. However, as will be understood, other orientations of the platform and the base are possible. For instance, the platform can be arranged to the side of the base.

The platform and the base could each be configured to be moveable relative to the machine structure. The base could be moveable relative to the machine structure in at least one linear degree of freedom. The base could be moveable relative to the machine structure in at least one rotational degree of freedom. Preferably, the base is fixed relative to the machine structure. Preferably, the platform is moveable relative to the machine structure and hence moveable relative to the base.

The machine structure can comprise at least one actuator for moving the platform. The actuator could act directly on the platform. Optionally, the actuator could act on a part connecting the platform and the machine structure. For instance, the actuator could act on a telescopic strut extending between the platform. The machine structure can comprise at least one actuator for moving the base. Likewise, the actuator could act directly on the base or on a part connecting the base and machine structure. Preferably the at least one actuator is operable under the control of an electronic position input device. Suitable actuators include motors, such as electric motors.

Many suitable electronic position input devices are available for inputting a demanded relative position. The electronic position input device can be a memory device which contains pre-stored demanded relative positions. Optionally, the electronic position input device can be a processor unit, for instance a general purpose computer which can provide demanded relative positions from a computer program.

The machine structure can comprise at least one position sensing device for determining the position of the platform relative to the machine structure. If the base is moveable relative to the machine structure, preferably the machine structure comprises at least one position sensing device for determining the position of the base relative to the machine structure. The position sensor could be located on a part connecting the platform and machine structure. For instance, the position sensor could be configured to monitor the extension of a telescopic strut, the position of the platform being derivable therefrom. The at least one position sensing device could be configured to provide position information which can be provided to the electronic position input device to determine the relative position of the platform and machine structure. Accordingly a feedback loop can be provided for the accurate control of the movement of the platform.

Suitable position sensors include those that utilise a scale and a readhead for reading the scale. Suitable scales include those having marks defining a pattern which can be read by a readhead in order to determine relative movement between them. For instance, the scale can be an incremental scale having scale marks defining a periodic pattern which generates a periodic signal at the readhead when relative movement between the scale and readhead take place. These periodic signals produce an up/down count which enables displacement between the scale and the readhead to be determined. For instance, such a suitable scale is described in European Patent Application no. 0207121, the entire content of which is incorporated into the specification of the present application by this reference. The scale can have reference marks which are detectable by the readhead so that it can determine the exact position of the readhead relative to the scale. For example, such a scale is disclosed in Published International Patent Application WO 2005/124282, the entire content of which is incorporated into the specification of the present application by this reference. Optionally, the scale can be an absolute scale which has scale markings which enable the readhead to determine an exact absolute position relative to the scale without the need to incrementally count from a predetermined position. Such scales typically have scale markings which define unique position data. The data can be in the form of, for instance, a pseudorandom sequence or discrete codewords. Such a scale is disclosed in International Patent Application no. PCT/GB2002/001629, the entire content of which is incorporated into the specification of the present application by this reference.

Furthermore, the machine structure can comprise at least one sensor for determining the direct mechanical output of the at least one actuator. This is so that the performance of the at least one actuator can be monitored. For example, a sensor can be provided for determining the direct output of the motion inducing part of the actuator. As will be understood, the motion inducing part of an actuator can be, for example, the source of motion within the actuator, or a part directly connected to the source such that there is no mechanical flexibility between them. For instance, the sensor can determine the velocity of the actuator. For example, the sensor can determine the output velocity of the actuator. For example, in embodiments in which the actuator is a motor having a rotating drive shaft, there can be provided a tachometer for measuring the rotational speed of the drive shaft. The at least one sensor can be configured to provide an output to the electronic position input device so that it can determine the performance of the at least one actuator and take corrective action if necessary. This can provide a much tighter feedback loop for accurately controlling the velocity of the platform or base than compared to using the output of the position sensors which look at the position of the platform or base. Accordingly the accuracy by which the platform or base can be moved is improved which is advantageous when the machine structure is used as a machine tool.

Preferably, the platform is moveable relative to the base in at least two degrees of freedom, more preferably at least three degrees of freedom. Preferably, the platform is moveable relative to the base in at least two perpendicular linear dimensions, more preferably at least three mutually perpendicular linear dimensions. The platform could be moveable relative to the base in at least one rotational degree of freedom. However, it can be preferred in some circumstances to configure the platform such that it is constrained from rotating relative to the base in at least one rotational degree of freedom. It can be preferred that the platform is constrained from rotating about at least one rotational axis, more preferably about two perpendicular rotational axes, especially preferably about three mutually perpendicular rotational axes.

The first and second repeatable mount formations could be identical to each other. This provides enhanced flexibility as to on which of the platform and base a part, such as a metrological device, object support or tool holder can be mounted.

In some circumstances it can be advantageous to control which part(s) can be mounted on the platform and which part(s) can be mounted on the base. In this case, the machine structure and/or the metrological device, object support and tool holder can be configured to detect whether the metrological device, object support and tool holder is mounted on the platform or base and provide a warning to the user when it is mounted on the wrong one. For instance, each of the metrological device, object support and tool holder can have a unique identification feature, such as a physical feature which engages a sensor feature on the platform or base, or an electronic tag which is readable by a sensor in the platform or base (for instance via radio-frequency identification technology, commonly known as RFID technology). A control unit could thereby determine whether what is mounted on the base or platform should not be mounted and if so provide an output, such as an audible or visual output, which warns the user that the machine structure apparatus is incorrectly setup.

Optionally, features can be provided on at least one of the first and second repeatable mount formations, and/or on at least one of the metrological device, object support and tool holder which restrict which of the platform and base the metrological device, object support and tool holder can be mounted on.

Optionally, the first and second repeatable mount formations can be different in configuration to each other. In this case, preferably, the metrological device's repeatable mount formations are for cooperation with the second repeatable mount formations only. Preferably, the tool holder's repeatable mount formations are for cooperation with the first repeatable mount formations only. Accordingly, in this case, the metrological device can be mounted only on the platform and the tool holder can be mounted only on the base. This prevents the parts being mounted on the incorrect mount.

The object support can be configured to hold a sample to be inspected by the metrological device. The object support can be configured to hold a workpiece to be worked on by a tool in the tool holder. Accordingly, the same object support could be used to hold either a sample or a workpiece.

Preferably, a second object support is provided having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations. Preferably the second object support is configured to hold a workpiece to be worked on by a tool held in the tool holder.

In this case, preferably, the object support is for holding a sample to be examined by metrological device. Accordingly, preferably the object support's repeatable mount formations are for cooperation with the first repeatable mount formations on the base. Preferably, the second object support is for holding a workpiece to be worked on by a tool in the tool holder. Preferably, the second object support's repeatable mount formations are for cooperation with the second repeatable mount formations on the platform.

Accordingly, in a particularly preferred embodiment, the metrological device is for suspending from the platform to scan an object mounted on a sample holder which is mounted on the base. Furthermore, preferably the tool holder is configured to sit on the base such that a tool held in the tool holder is substantially upstanding. This is advantageous as during operation, dust and debris caused by a tool held in the tool holder working on a workpiece suspended from the platform falls away from the platform due to gravity.

The tool holder comprises a part for holding a tool and a part for causing actuation of the tool. The tool holder can further comprise the tool. Accordingly, the tool holder can be provided with a permanently fixed tool. Preferably the tool holder comprises a chuck for releasably holding a tool. Accordingly, preferably the different tools can be used with the tool holder. Preferably, the tool holder comprises a spindle for facilitating turning of the chuck. Preferably, the tool holder comprises an actuator for turning a tool held in the tool holder. Preferably, the tool holder comprises a motor for turning a tool held in the tool holder. The motor could be an electrically powered motor. The motor could be an air powered motor.

Preferably, the tool holder comprises at least one conduit through which an air flow can be pulled to remove dust, swarf and the like from the machine structure's operating volume. Preferably, the conduit extends at least part annularly around the axis about which a tool held in the tool holder is rotated. Preferably, the conduit extends substantially annularly around the axis about which a tool held in the tool holder is rotated. Preferably, the conduit has an opening at the chuck. Preferably, the opening extends at least part annularly around the chuck. Preferably, the opening extends substantially annularly around the chuck.

The conduit in the tool holder can be connected directly to an extraction unit which can pull the flow of air. Optionally, the base of the machine structure comprises at least one conduit for fluidly connecting the at least one conduit in the tool holder to an extraction unit.

As described above in connection with the first aspect of the invention, preferably, the platform comprises at least one connector for electrically connecting to at least one corresponding connector on the metrological device. Furthermore, preferably the base comprises at least one connector for electrically connecting to at least one corresponding connector on the tool holder.

According to a third aspect, the invention provides a tool holder for holding and actuating a workpiece shaping tool, the tool holder having repeatable mount formations for cooperation with repeatable mount formations on a machine tool apparatus.

Preferably, the repeatable mount formations are kinematic mount formations.

The tool holder can be configured in accordance with the tool holder described above in connection with the second aspect of the invention.

The application also describes a machine tool for machining a dental prosthesis, comprising: a platform from which a workpiece can be suspended; a spindle for holding and rotating a tool for removing material from a workpiece suspended from the platform, the spindle configured such that a tool held therein is substantially upstanding such that during operation, dust and debris caused by a tool held in the spindle working on a workpiece suspended from the platform falls away from the platform due to gravity; and an actuator for moving the platform relative to the spindle in at least first and second degrees of freedom that extend perpendicular to the axis of rotation of the spindle.

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

Figure 1 shows an isometric view of a machine structure according to the present invention;

Figure 2 shows an isometric view of the machine structure shown in Figure 1 setup for use as a scanning machine;

Figure 3 shows an isometric view of the machine structure shown in Figure 1 setup for use as a milling machine;

Figure 4 shows the moveable platform of the machine structure shown in Figure 1;

Figure 5 shows a contact probe for mounting on the platform shown in Figure 4;

Figure 6 shows a workpiece holder for mounting on the platform shown in Figure 4;

Figure 7 shows the base of the machine structure shown in Figure 1;

Figure 8 shows the underside of a sample holder for mounting on the base shown in Figure 7;

Figure 9 shows the underside of a tool holder for mounting on the base shown in Figure 7;

Figure 10 is an exploded view of the tool holder shown in Figures 3 and 9; and

Figure 11 is a schematic system diagram.

Referring to the Figures, Figure 1 shows a machine structure according to the present invention generally indicated by reference numeral 2. The machine structure 2 generally comprises a body 4 having a fixed base 6 and a fixed head 18, mounted to which is a platform 8 that is generally opposite to and facing the fixed base 6.

The platform 8 is coupled to the head 18 of the body 4 via three telescopic struts 20, each strut being connected to the platform 8 and the head 18 of the body at its respective upper and lower ends by pivot joints. Each strut 20 has a motor 16 to increase or decrease its length. Each motor 16 comprises a tachometer for measuring the rotational speed of the drive shaft in the motor. Furthermore, a scale 17 and a readhead 19 for reading the scale 17 is provided on the back of each strut 20. The outputs of the tachometers and readheads are provided to the computer 100 for use in a feedback loop to enable accurate control of the movement of the platform as described in more detail below.

As the platform 8 is supported only by the three telescopic struts 20 which are connected to the upper and lower stages by ball joints, this platform may rotate about three perpendicular axes relative to the head 18. To prevent this, three anti-rotational devices 12, comprising a pair of struts 22 and a rotation restrictor (not shown), are provided which eliminate these three degrees of rotational freedom whilst allowing translational movement. The devices are passive, i. e. they have no motor or other actuator. The joints between the anti-rotational devices 20 and the platform 8 and the head 18 are also ball joints. Accordingly, the struts 20 and anti-rotational devices facilitate movement of the platform 8 relative to the body 4 in three mutually perpendicular dimensions (i.e. x, y and z dimensions), under the control of a computer 100 (described more detail below in connection with Figure 11). Such an arrangement for providing linear-only relative movement of a platform 8 relative to a fixed head 18 is known, and described for example in EP 0674969 and US 7241070, the entire contents of which are incorporated by these references. As will be understood, mechanisms other than the one described above can be used for facilitating relative movement between the platform 8 and the head 18. In particular, it need not be necessary to restrict rotation of the platform 8 relative to the head 18. Furthermore, a mechanism could be used which only permits movement of the platform 8 in one dimension, with relative movement between the platform 8 and base 6 being achieved by facilitating movement of the base 6.

Referring to Figure 4, the platform 8 comprises a first set of kinematic mount formations 36. The first set of kinematic mount formations 36 comprise three features 38 in the form of hemispheres projecting from a plate 40 on the platform 8 at three spaced apart locations. The features 38 are formed by mounting highly spherical balls within circular recesses in the platform 8. As will be understood types of kinematic mount formations other than the described hemispheres can be used. The plate 40 further comprises a magnet 41 for attracting a corresponding magnet 55 in the plate 54 of the probe 24 and a corresponding magnet 71 in the plate 70 of the workpiece holder 30 (as described in more detail below). The plate 40 also comprises a plurality of floating pin electrical contacts 43 for connecting to corresponding fixed pad electrical contacts 45 on the plate 54 of the probe 24. The electrical contacts 43, 45 enable electrical power to be supplied to the probe 24, and data to be communicated between the probe 24 and the computer 100 when the probe 24 is mounted on the platform 8. As the electrical contacts 43 are floating pin electrical contacts, they can accommodate manufacturing tolerances in the mounting of the fixed pad electrical contacts 45 on the probe 24 by moving in and out of the plate 40, thereby not interfering with the mounting of the probe 24 on the platform 8.

Referring to Figure 7, the base 6 comprises a second set of kinematic mount formations 42. The second set of kinematic mount formations 42 comprise three pairs of features 44 in the form of hemispheres projecting from the base 6. Each pair of hemispheres 44 define a pair of mutually converging surfaces at three spaced locations. The base 6 also comprises a conduit having three arc-shaped openings 46 on its side facing the platform 8. As shown, the openings 46 extend between the pairs of hemispheres 44. Also as shown, the openings 46 protrude from surface of the base 6. A further opening (not shown) is provided on the side of the base 6 facing away from the platform 8 such that the conduit can be connected to an extraction system 102 via an extraction line 104 as shown in Figure 11 and described in more detail below. The base 6 further comprises three magnets 7 for attracting three corresponding magnets 27 on the underside of the sample holder 26 and three corresponding magnets 81 in the base 80 of the tool holder 32 (as described in more detail below). The base 6 also has a plurality of floating pin electrical contacts 73 for connecting to corresponding fixed pad electrical contacts 75 on the base 8 of the tool holder 32. The electrical contacts 73, 75 enable electrical power to be supplied to the motor in the tool holder 32 when it is mounted on the base 6 of the machine structure 2. As the electrical contacts 73 are floating pin electrical contacts, they can accommodate manufacturing tolerances in the mounting of the fixed pad electrical contacts 75 on the tool holder 32 by moving in and out of the base 6, thereby not interfering with the mounting of the tool holder 32 on the base 6 of the machine structure. As illustrated in Figure 2, the machine structure 2 can be setup for use as a scanning machine and as illustrated in Figure 3 the same machine structure 2 can be setup for use as a machine tool.

Referring in particular to Figure 2, when the machine structure 2 is setup for use as a scanning machine, there is provided a contact probe 24 mounted on the platform 8 and a sample holder 26 mounted on the base 6.

As shown in more detail in Figure 5 the contact probe 24 comprises a probe body 46, a stylus module 48 mounted to the probe body 46 via corresponding kinematic mounts (not shown) and a stylus 50 having a workpiece contacting stylus tip 52. The stylus 50 is mounted to the stylus module via corresponding kinematic mounts (not shown). Typically, the probe body 46 houses sensor and electronics for detecting the deflection of the stylus 50 and the stylus module 48 houses components which facilitate the pivoting of the stylus 50 relative to the probe body 46. The use of modular contact probe 24 enables the use of different stylus and stylus modules with the same probe body 46. Modular contact probes 24 are known and for instance are described in US 6772527 the entire content of which is incorporated in this specification by this reference. However, as will be understood the use of modular probes are not essential to the invention and non-modular probes are also suitable for use with the present invention.

The probe 24 has a plate 54 fixed to the probe body 46. The plate 54 provides kinematic mount formations in the form of three pairs of hemispheres 56 each pair projecting from the platform at spaced locations. Each of the three pairs of hemispheres 56 define a pair of mutually converging surfaces at three spaced locations, in such a manner as to provide a total of six rigid points of contact with the three hemispherical projections 38 on the platform. This constrains the six possible degrees of freedom of the probe 24 relative to the platform 8. The plate 54 further comprises a magnet (not shown) which is attracted to the magnet in the plate 40 of the platform 8 so as to urge the kinematic mount formations together thereby rigidly holding the probe 24 on the platform 8. As described above, electrical contacts 45 are provided for electrically connecting the probe 24 to the computer 100 via the electrical contacts 43 on the platform 8.

Referring to Figures 2 and 8, the sample holder 26 comprises a clamp 28 for holding a sample to be inspected, the clamp 28 being tightened and loosened by way of the knob 29 provided on the sample holder 26. As shown in Figure 8, the underside of the sample holder 26 provides kinematic mount formations in the form of three hemispheres 58 projecting from the sample holder at spaced locations. Each of the three hemispheres 58 are arranged to be received in the pair of mutually converging surfaces defined by the pairs of hemispheres 44 on the base 6 of the machine structure 2, in such a manner as to provide a total of six rigid points of contact with the three hemispherical projections 58 on the sample holder 26. This constrains the six possible degrees of freedom of the sample holder 26 relative to the base 6. The underside of the sample holder 26 also provides three openings 60 for fitting over the arc-shaped protruding openings 46 on the base. The underside of the sample holder 26 further comprises a magnet (not shown) which is attracted to the magnet in the base 6 of the machine structure so as to urge the kinematic mount formations together thereby rigidly holding the sample holder 26 on the base 6.

Accordingly, when the probe 24 and the sample holder 26 are mounted onto the platform 8 and the base 6 respectively via their corresponding kinematic mounts, the contact probe 24 can be moved by the platform 8 under the control of a computer 100 (shown in Figure 11 and described in more detail below) into contact with a sample (not shown) which is held in the clamp part 28 of the sample holder 26, in order to obtain data on the shape of the sample. Techniques and technologies for scanning samples via measurement probes are well known and the particular technique and technology used is not relevant to the present invention and so will not be described further. As will be understood, although the measuring device described in the present embodiment is a contact probes it will be understood that this need not necessarily be the case. For instance, a non-contact probe could be used for scanning a sample held in the sample holder.

As illustrated in Figure 3, the machine structure 2 can be setup for use as a machine tool for machining a part from a workpiece. In this case, there is provided a workpiece holder 30 mounted on the platform 8, and a tool holder 32 mounted on the base 6.

As shown in more detail in Figure 6, the workpiece holder 30 comprises a frame, generally indicated by reference numeral 62 having opposing first 64 and second 66 arms between which a workpiece mount 68 can be releasably held via corresponding engagement formations (not shown). The corresponding engagement formations enable the workpiece mount 68 to be rotated about an axis A defined by the engagement formations, such that a workpiece held in the workpiece mount 68 can be turned upside down. The workpiece mount 68 defines an area 74 in which a workpiece (not shown) from which a dental part can be machined can be clamped by the workpiece mount 68. The frame 64 and workpiece mount 68 are disclosed in the co-pending PCT application filed on the same day as the present application with the title Indexer, having the applicant's reference number 0772/WO/0 and claiming priority from UK Patent Application no. 0803666.7. Subject matter that is disclosed in that application is incorporated in the specification of the present application by this reference.

The workpiece holder 30 also comprises a plate 70 fixed to the frame 62. The plate 70 provides kinematic mount formations in the form of three pairs of hemispheres 72 each pair projecting from the platform at spaced locations. Each of the three pairs of hemispheres 72 define a pair of mutually converging surfaces three spaced locations, in such a manner as to provide a total of six rigid points of contact with the three hemispherical projections 38 on the platform. This constrains the six possible degrees of freedom of the frame 62 relative to the platform 8. The plate 70 further comprises a magnet (not shown) which is attracted to the magnet in the plate 40 of the platform 8 so as to urge the kinematic mount formations together thereby rigidly holding the workpiece holder 30 on the platform 8.

As shown in more detail in Figures 9 and 10, the tool holder 32 comprises a spindle housing 76, a chuck 78, a base 80 for rigidly mounting the spindle housing 76 to the base 6 of the machine structure 2 (as described in more detail below), a funnel 82 and a dust guard 84.

The spindle housing 76 houses a spindle (not shown) for turning the chuck 78 which holds the tool 34 (see Figure 10). As will be understood, the spindle axis is coaxial with chuck 78. The spindle is powered by an external electrical power source connected to the spindle via the electrical connections 73, 75. The spindle housing 76 further comprises a conduit extending annularly around the spindle between the ends of the spindle housing 76. The conduit has first 86 and second 88 openings at its end proximal the chuck 78 and first 90, and third an opening 112 at its opposite end that extend substantially annularly around the spindle housing 76.

As shown in Figure 9, the base 80 of the tool holder 32 provides kinematic mount formations in the form of three hemispheres 114 projecting from the base at spaced locations. Each of the three hemispheres 114 are arranged to be received in the pair of mutually converging surfaces defined by the pairs of hemispheres 44 on the base 6 of the machine structure 2, in such a manner as to provide a total of six rigid points of contact with the three hemispherical projections 114 on the base 80 of the tool holder 32. This constrains the six possible degrees of freedom of the tool holder 32 relative to the base 6 of the machine structure 2. The base 80 of the tool holder 32 also provides three openings 90 for connecting to the third opening 112 in the spindle housing 76 and the three openings 46 in the base 6 of the machine structure so as to fluidly connect the conduit in the spindle housing 76 and the conduit in the base of the machine structure 2. The base 80 of the tool holder 32 further comprises a magnet (not shown) which is attracted to the magnet in the base 6 of the machine structure 2 so as to urge the kinematic mount formations together thereby rigidly holding the tool holder 32 on the base 6 of the machine structure 2.

The funnel 82 comprises a frusto-conical wall 96 which at its narrow end fits tightly onto the end of the spindle housing 76 proximal the chuck 78 so as to provide an air tight seal between the walls of the narrow end of the funnel 82 and the spindle housing 76. Also provided at the narrow end of the funnel 82 are first 98 and second 100 openings for connecting to the first 86 and second 88 openings in the spindle housing. A conical nose portion 102 having an opening 104 at its tip is provided upstanding from the narrow end of the funnel 82 and is configured such that when the funnel 82 is fitted onto the spindle housing 76, the tool 34 protrudes through the opening 104 of the conical nose portion 102.

The dust guard 84 comprises a frusto-conical base 106 and a concertinaed resiliently compressible tube 108 defining an opening 110. The dust guard 84 is configured such that the wide end of the frusto-conical base 106 sits halfway across the first 98 and second 100 openings such that a fluid path exits between the conduit in the spindle housing 76 and the opening 110 in the concertinaed resiliently compressible tube 108, and also the conduit in the spindle housing 74 and the volume surrounding the dust guard 84. The concertinaed resiliently compressible tube 108 is compressible parallel to the axis of rotation of the spindle in the spinde housing 76. Furthermore, the open end of the concertinaed resiliently compressible tube 108 is rigid such that the open end cannot bend, thereby helping to ensure that the opening 110 is always wholly contained in a plane.

Accordingly, when the tool holder 32 and the workpiece holder 30 are mounted on the base 6 and the platform 8 respectively, the workpiece holder 30 can be driven by the platform 8, under the control of a computer 100, into contact with a milling tool 34 (not shown in Figure 3) which is held in the tool holder 32, in order to shape the workpiece into a desired shape. As will be understood, tools other than milling tools can be used with the tool holder 32 described. For instance, the tool holder 32 could hold a drilling or grinding tool. Techniques and technologies for machining workpieces, via milling, drilling and/or grinding are well known and the particular technique and technology used is not relevant to the present invention and so will not be described further.

Referring to Figure 11, there is shown a machine structure 2 according to the present invention setup for use as a machine tool. In particular, the machine structure 2 has a workpiece holder 30 mounted on the platform 8 and a tool holder 32 mounted on the base 6. The machine structure 2 is connected to a computer 100 via an electrical cable 120. In particular, the computer 100 comprises machine control software 122 which controls the platform's motors 16 to move the platform.

During the scanning of a part (i.e. when the machine structure is set up as a scanning machine as shown in Figure 2) the machine control software 122 need only use the position information received from the readheads 19 to determine and control the position of the platform. However, in order to achieve tighter control over the position of the platform during machining, the machine control software 122 can also use the information from the tachometers in the motors 16 in order to ensure that the platform is moved in the desired way. As will be understood, actually monitoring the direct output/performance of the motor itself (e.g. by, in the current embodiment, using a tachometer) rather than determining how the platform is moving (e.g. by, in the current embodiment, using readheads and scale on the struts) can provide a much tighter feedback loop which is preferable for machining operations. Nevertheless, in either case, a feedback loop exists so that the machine control software 122 can control the movement of the platform 8 inline with the accuracy requirements determined by a scanning operation or a machining operation.

The machine control software 122 uses data from CAM software 124 in the computer 100 so as to determine how to control the movement of the platform 8 and hence movement of a workpiece (not shown) held in the workpiece holder 30. For instance, the CAM software 124 can provide to the machine control software 122 model data of a dental prosthesis which the machine control software 122 uses in order to control the platform 8 so as to create a replica dental prosthesis from the workpiece (not shown) held in the workpiece holder 30. As illustrated, the CAM software 124 can receive its data from a plurality of sources, and for example can receive data from a scanning machine which has scanned a dental part. The scanning machine could be a dedicated scanning machine or a machine structure according to the present invention setup as a scanning machine. Furthermore, the scanning machine can be the same machine structure 2 shown in Figure 2 wherein the data has been previously obtained whilst the machine structure 2 was set up as a scanning machine. Furthermore, the data can be received from another computer over the internet. Alternatively, the data could have been obtained from a computer model rather than having been obtained by scanning a physical part.

The computer 100 can also be connected to the tool holder 32 so as to control the operation of the spindle in the spindle housing 76 and hence control the turning of a tool held in the tool holder 32.

The machine structure 2 is connected to an extraction system 102 via an extraction line 104. The extraction line 104 provides a fluid connection between the conduit in the base 6 and the extraction system 104. Accordingly, when assembled, a flow path exists between the extraction system 102 and the working volume of the machine structure 2 via the extraction line 104, the conduit in the base 6 of the machine structure 2, the conduit in the tool holder 32 (connected to the conduit in the base 6 by the openings 40 in the base 6 of the machine structure 2 and the openings in the base 80 of the tool holder 32), the first 86 and second 88 openings in the funnel 82 and the opening 110 in the dust guard 84.

As will be understood, during machining of a dental part from a workpiece held in the workpiece holder 30 dust, chips and swarf will be generated. However, a significant amount of such dust and debris will be contained by the concertinaed resiliently compressible tube 108. In use, the open end of the resiliently compressible tube 108 (i.e. the end that defines the opening 110) contacts the workpiece (not shown) when the workpiece is brought into contact with the tool held in the tool holder 32. The dust guard 32 is configured such that in order to bring the workpiece into contact with the tool held in the tool holder 32, the concertinaed resiliently compressible tube 108 is compressed against the workpiece thereby forming a seal between the inside of the concertinaed resiliently compressible tube 108 and the atmosphere surrounding the machine structure 2. Dust contained within the dust guard 84 will be pulled into the extraction system via the conduits defined by the dust guard 84, funnel 82, spindle housing 76, base 6 of the machine structure and extraction line 104. Any dust and debris which is not contained by the dust guard 84 will likely be caught by the funnel 82 and pulled into the extraction system 104 through the outside edge of the first 86 and second 88 openings and then via the conduits in the spindle housing 76 and base 6 of the machine structure 2.

When the machine structure 2 is setup as a scanning machine (i.e. as shown in

Figure 2), the extraction system need not be connected or operated. Furthermore, the machine control software 2 will control the platform 8 so as to cause the probe 24 to scan a sample held in the sample holder 26. Data from the probe 24 is collected by the machine control software and stored in memory for subsequent use, for instance for use during a machining process.

CLAIMS:

1. A machine structure apparatus for scanning and machining objects, the machine structure comprising a base and a platform moveable relative to the base, the base having first kinematic mount formations and the platform having second kinematic mount formations, such that an object support, a tool holder for holding and actuating a workpiece shaping tool and a measurement probe can be mounted on at least one of the first and second kinematic mount formations via corresponding kinematic mount formations, such that the machine structure can be used as a scanning machine or as a machine tool.

2. A machine structure apparatus as claimed in claim 1, in which the second kinematic mount formations are for the interchangeable mounting of an object support and a measurement probe.

3. A machine structure apparatus as claimed in claim 1 or 2 in which the first kinematic mount formations are for the interchangeable mounting of an object support and a tool holder for holding and actuating a workpiece shaping tool.

4. A machine structure apparatus as claimed in any preceding claim, in which the platform comprises at least one connector for electrically connecting to at least one corresponding connector on a measurement probe when mounted on the second kinematic mount formations.

5. A machine structure apparatus as claimed in any preceding claim, in which the base comprises at least one connector for electrically connecting to at least one corresponding connector on a tool holder when mounted on the first kinematic mount formations.

6. A machine structure apparatus as claimed in any preceding claim, in which the base of the machine structure further comprises at least one conduit for fluid

connection to at least one conduit in a tool holder when mounted on the first kinematic mount formations and in which the machine structure apparatus further comprises an extractor unit for connecting to the at least one conduit in the base.

7. A kit of parts comprising:

a machine structure having a base and a platform moveable relative to the base, the base and the platform having first and second repeatable mount formations respectively;

a metrological device having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations;

a tool holder for holding and actuating a workpiece shaping tool, the tool holder having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations; and

an object support having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations.

8. A kit of parts as claimed in claim 7, in which the repeatable mount formations are kinematic mount formations.

9. A kit of parts as claimed in claim 7 or 8, in which the first and second repeatable mount formations are different in configuration to each other.

10. A kit of parts as claimed in claim 9, in which the metrological device's repeatable mount formations are for cooperation with the second repeatable mount formations only and the tool holder's repeatable mount formations are for cooperation with the first repeatable mount formations only.

11. A kit of parts as claimed in any of claims 7 to 10, further comprising a second object support having repeatable mount formations for cooperation with at least one of the first and second repeatable mount formations.

12. A kit of parts as claimed in any of claims 7 to 11, in which the tool holder comprises a chuck for holding a workpiece shaping tool and a spindle for turning the chuck.

13. A kit of parts as claimed in any of claims 7 to 11, in which the tool holder comprises at least one conduit through which an air flow can be pulled to remove dust from the machine structure's operating volume.

14. A kit of parts as claimed in claim 13, in which the base of the machine structure further comprises a conduit for fluidly connecting the at least one conduit in the tool holder to an extractor unit.

15. A kit of parts as claimed in any of claims 7 to 14, in which the platform comprises at least one connector for electrically connecting to at least one corresponding connector on the metrological device when the metrological device is mounted on the second kinematic mount formations.

16. A tool holder for holding and actuating a workpiece shaping tool, the tool holder having repeatable mount formations for cooperation with corresponding repeatable mount formations on a machine tool apparatus.

17. A tool holder as claimed in claim 16, in which the tool holder comprises a spindle for rotating a tool.

18. A tool holder as claimed in claim 16 or 17, in which the repeatable mount formations are kinematic mount formations.

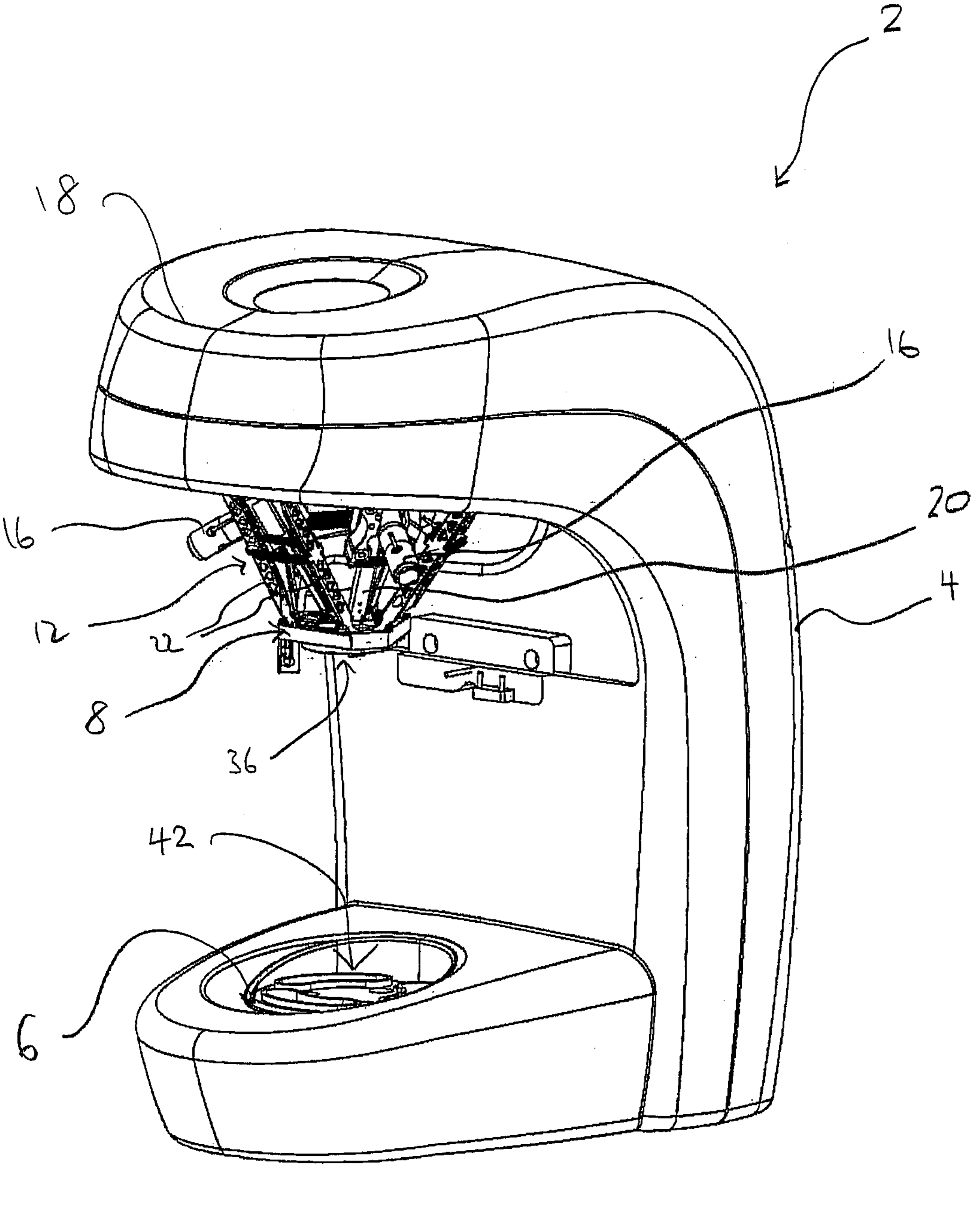

Fig 1

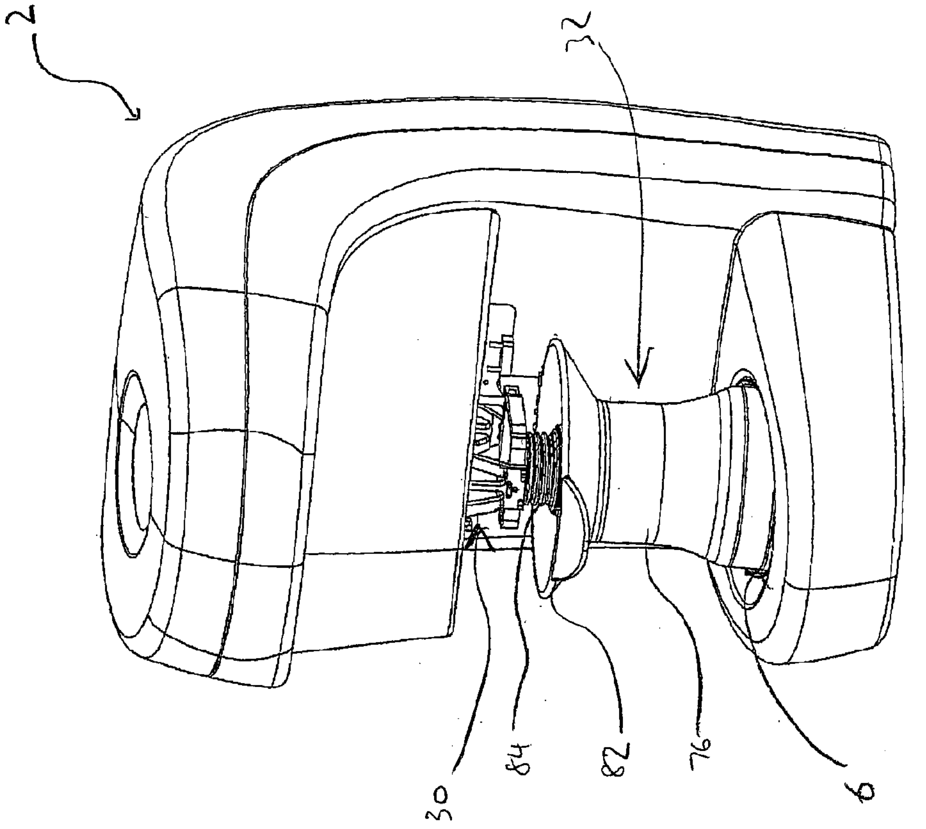

Fig 3

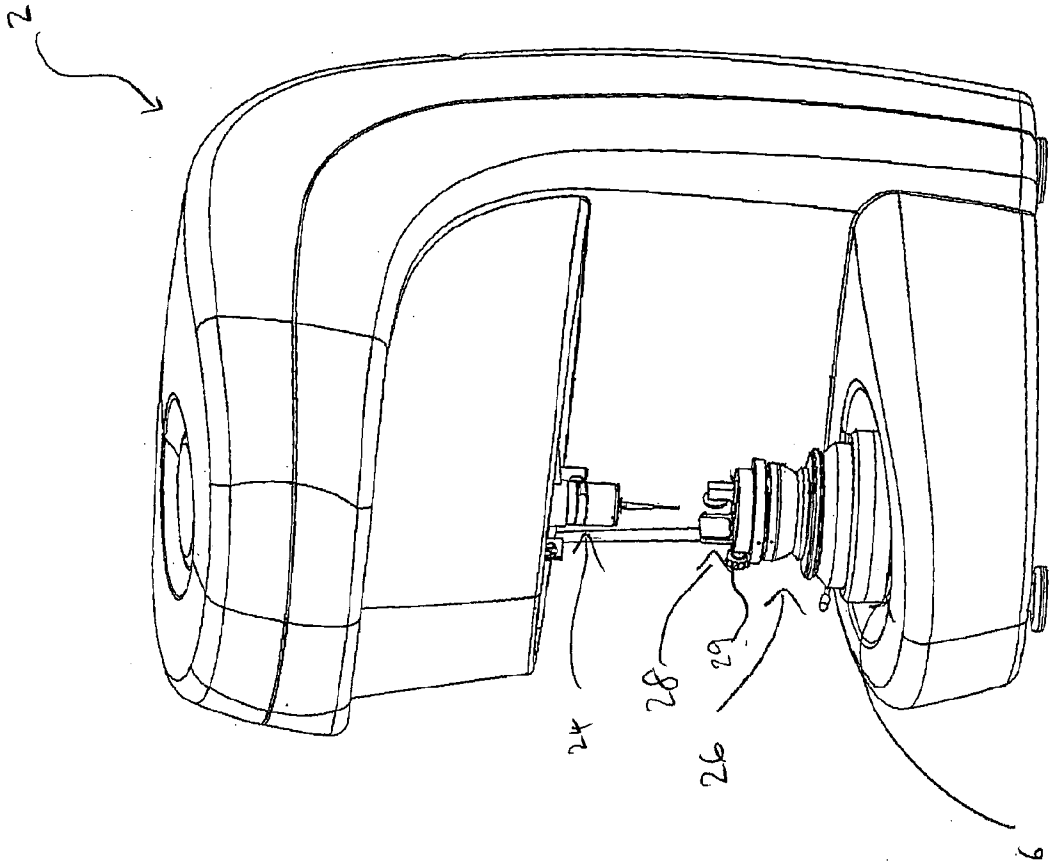

Fig 2

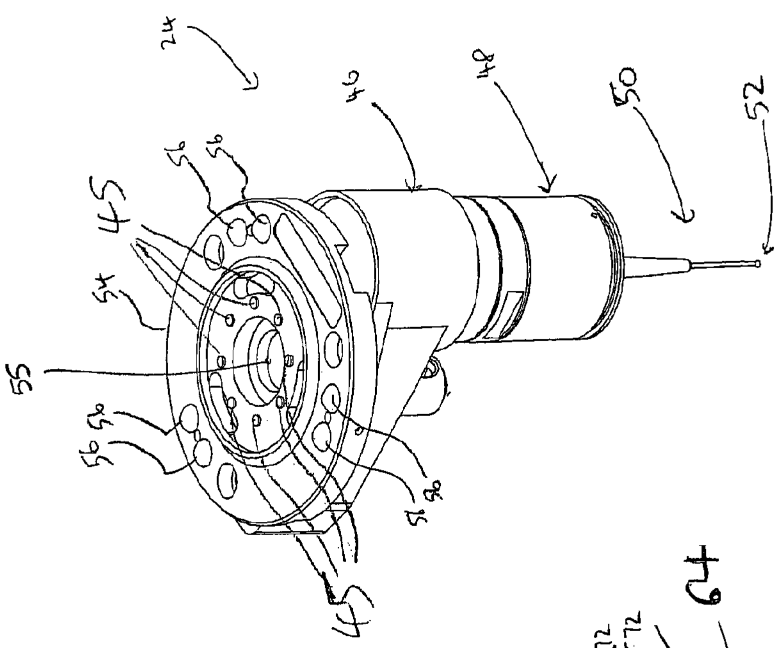

Fig 5

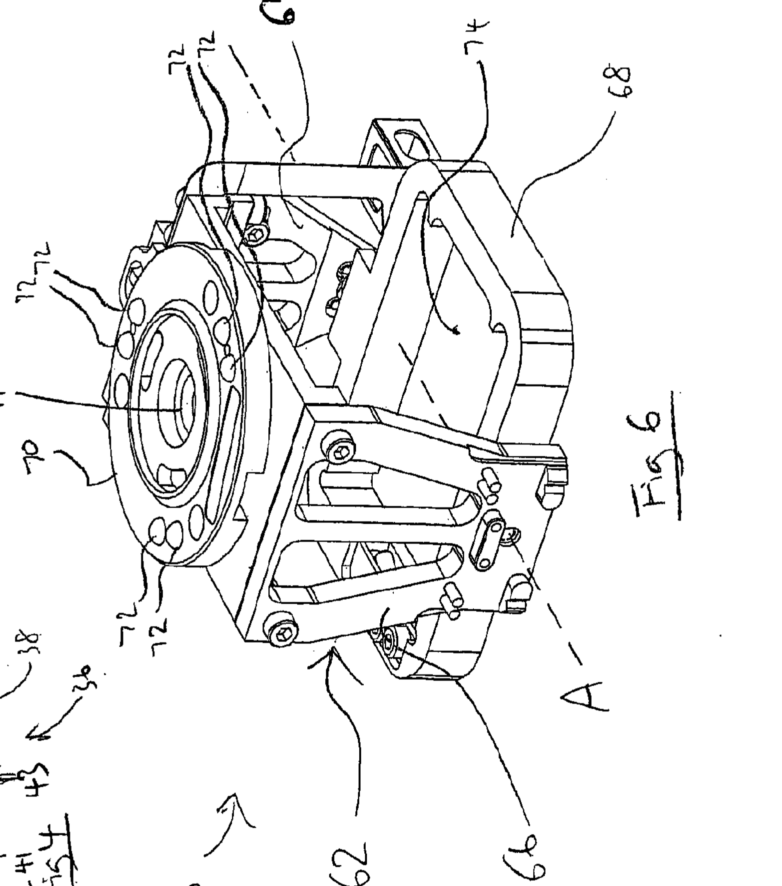

Fig 6

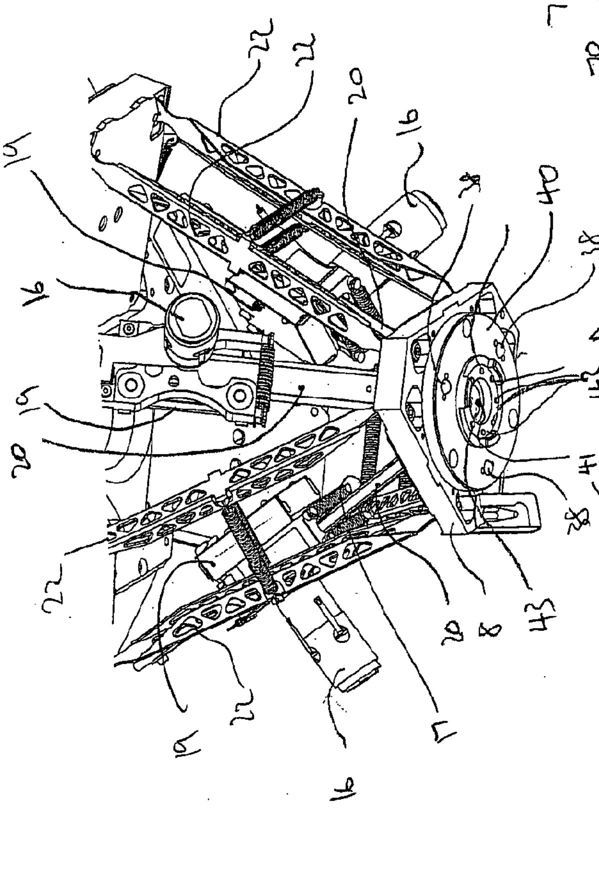

Fig 4

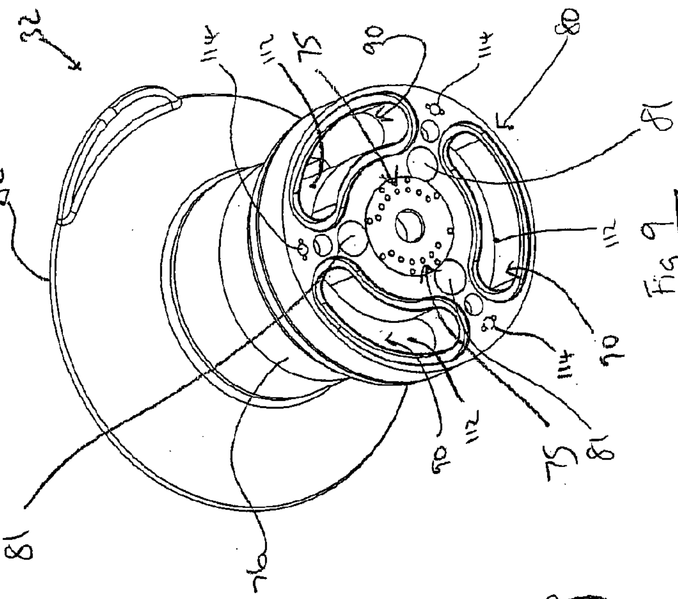

Fig 9

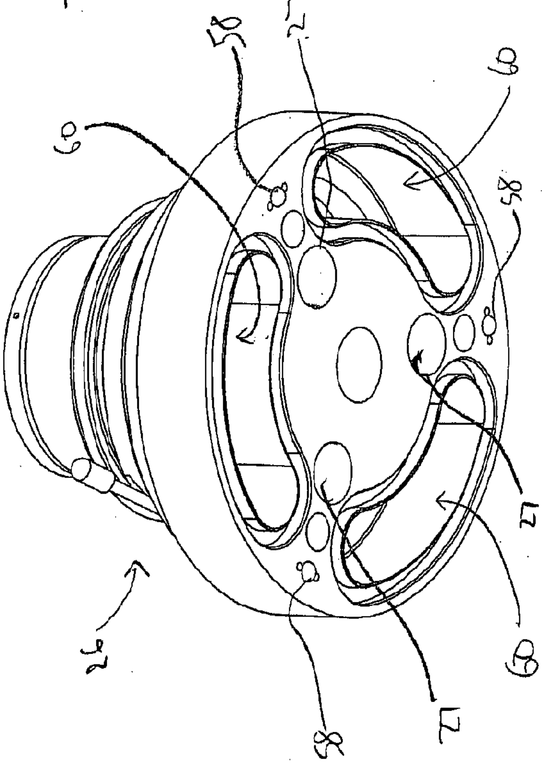

Fig 8

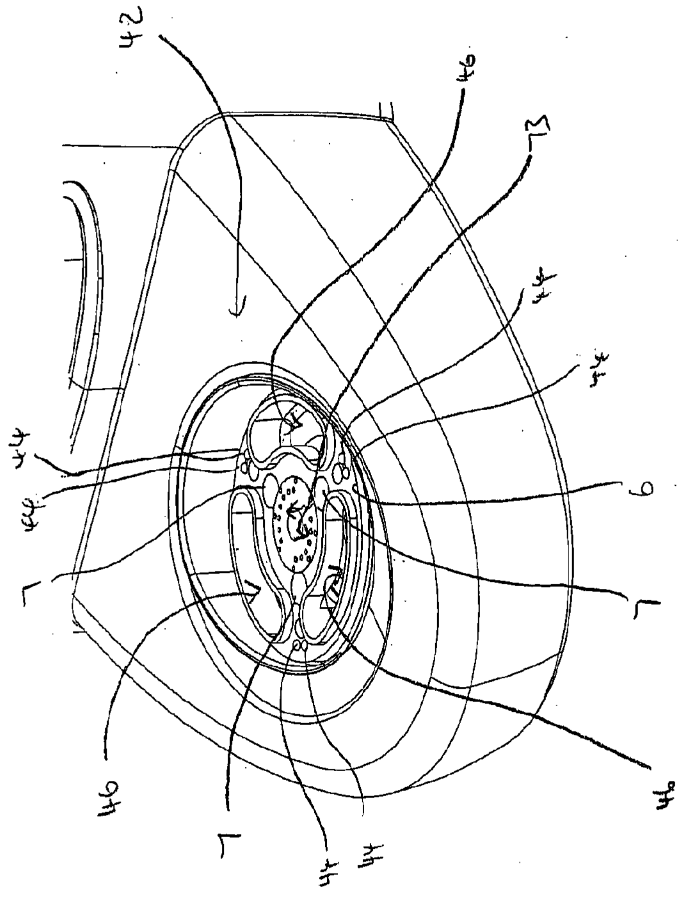

Fig 7

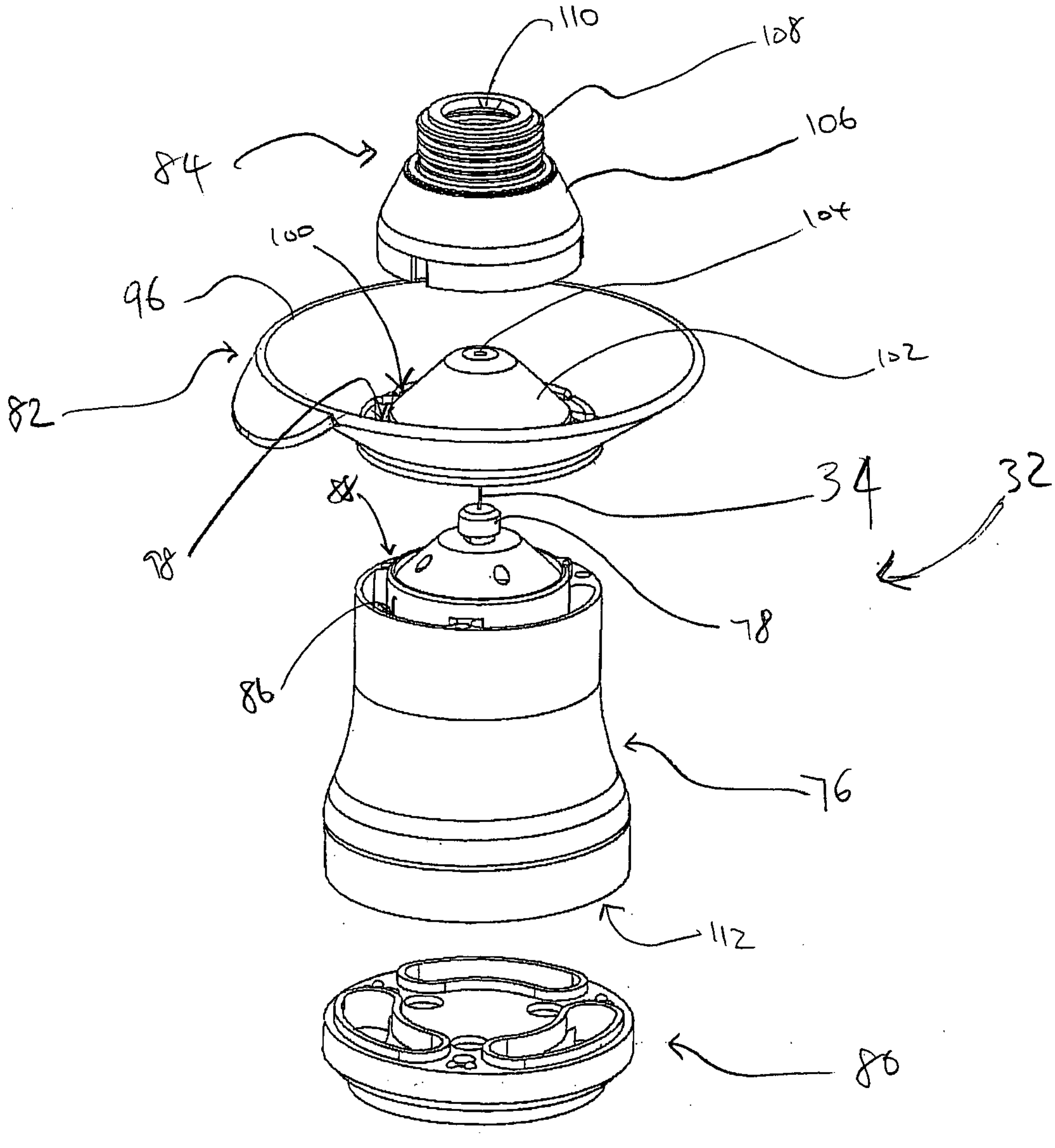

Fig 10

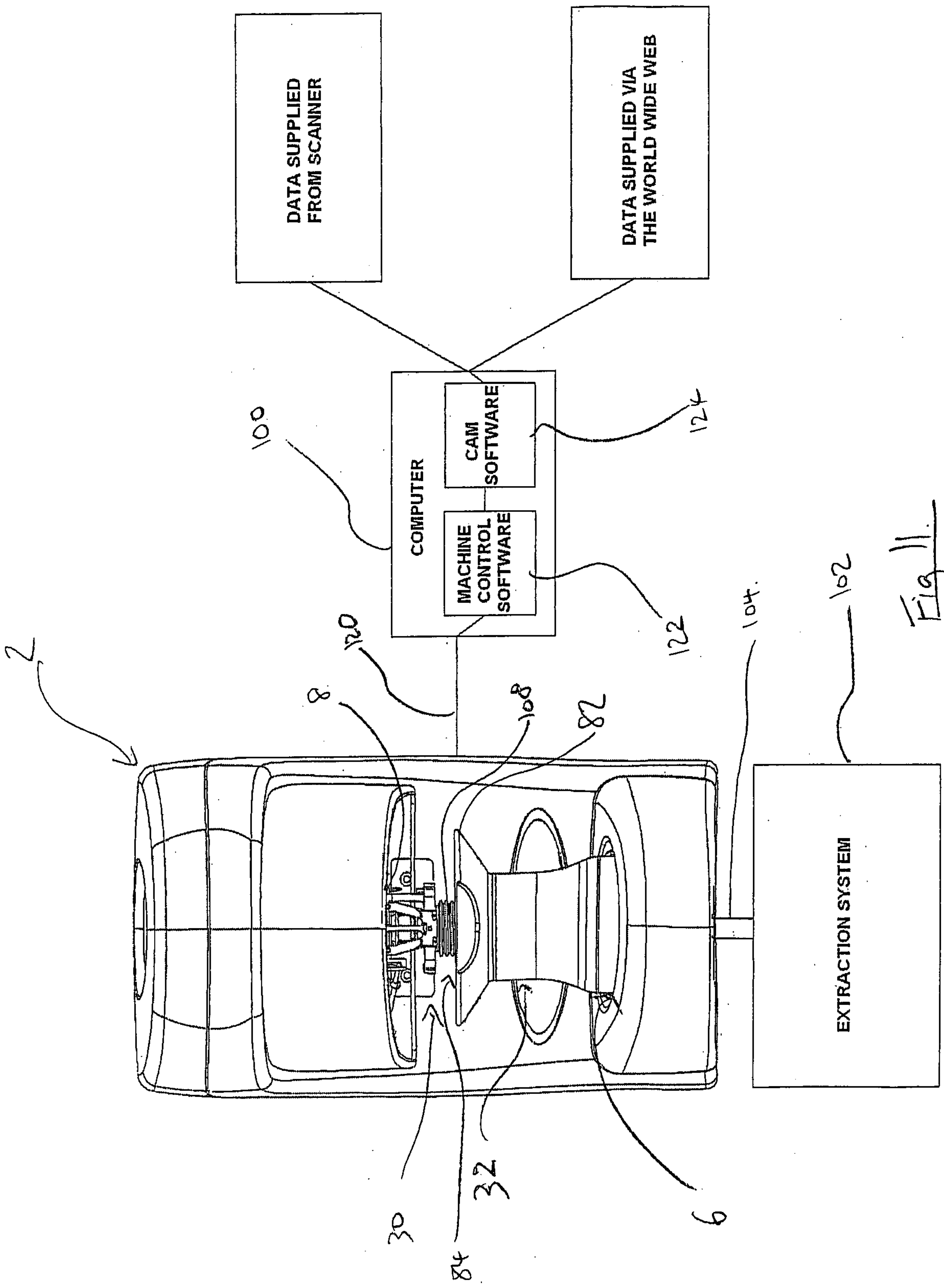
DATA SUPPLIED FROM SCANNER
DATA SUPPLIED VIA THE WORLD WIDE WEB
COMPUTER
CAM SOFTWARE
MACHINE CONTROL SOFTWARE
EXTRACTION SYSTEM
2
8
120
100
124
122
104
102
108
82
30
84
32
6

Fig 11.

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2009/000536

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61C13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61C G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97/49524 A1 (ADVANCE KK [JP]; SUGAI YASUHISA [JP]; HIROSAWA TAKASHI [JP]; SHIMURA K) 31 December 1997 (1997-12-31) abstract; figures 19A-31 -----	1-18
A	EP 1 293 174 A1 (ADVANCE KK [JP]) 19 March 2003 (2003-03-19) paragraphs [0101] - [0103], [115] - [0121], [128], [129] figures 5, 8, 9 -----	1,7
A	WO 2005/051595 A1 (RENISHAW PLC [GB]; HARDING ANDREW JAMES [GB]; THOMAS DAVID KENNETH [GB) 9 June 2005 (2005-06-09) page 6, line 9 - page 7, line 7 figures 14a-15 -----	1,7
	-/--	

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 June 2009	22/06/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chabus, Hervé

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2009/000536

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2009/000536

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