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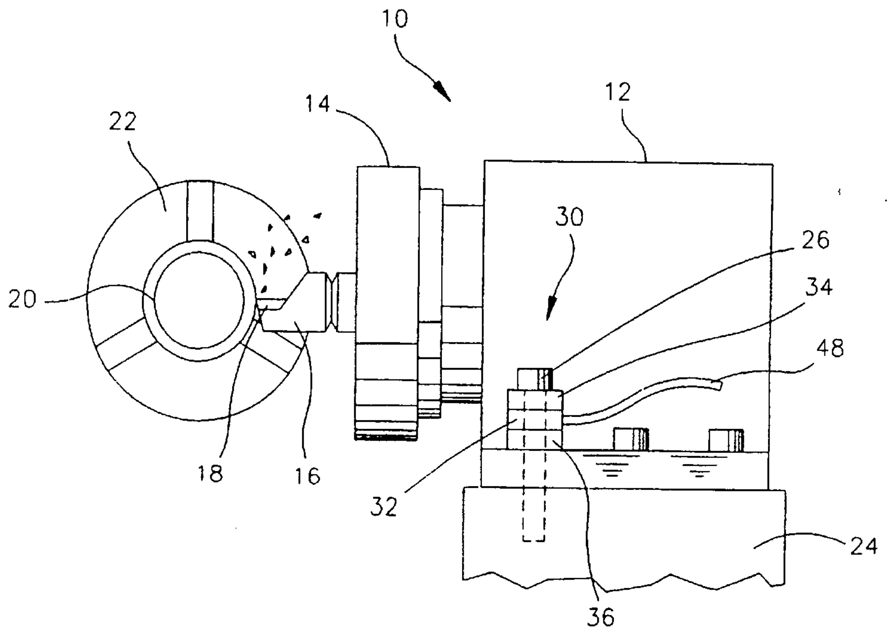


**(57) Abstract**

A method and apparatus for monitoring tool conditions during a machining operation utilizes a bolt transducer assembly (30) to monitor changes in tensile load on a bolt (26) securing two machine components (12, 24) together. During the machining operation, the cutting force loads of the interface of two machine components (12, 24) will vary as the cutting forces vary. A transducer assembly (30) is mounted in force transmitting relation between the threaded connector (26) and other machine components (12, 24). When the cutting force loads on the machine component increases, there will be a corresponding decrease in the tensile load on the bolt (26), and vice versa. The change in tensile load on the bolt (26) is continuously monitored to provide an indirect indication of the cutting forces on the machine tool (10). The output signal from the transducer (30) is used to extract information concerning the condition of the cutting tool (18).

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# BOLT TRANSDUCER AND METHOD FOR MONITORING CUTTING FORCES IN A MACHINE TOOL

## FIELD OF THE INVENTION

The present invention relates generally to adaptive control systems for a machine tool and more particularly to a method and apparatus for monitoring the condition of a tool during a machining operation.

## BACKGROUND OF THE INVENTION

In the operation of a machine tool, excessive wear of a cutting edge can have an adverse effect on the finish of a workpiece. Further, in modern high speed machinery, the cutting edge is often subjected to chipping or breakage as well as normal wear. in the past, tool condition was monitored by an experienced workman. However, the trend in the machine tool industry is towards complete automatic operation of the machine tool. On many machine tools, the cutting tool is partial or completely obscured by coolants, chips, machine components, workpiece fixtures, or the workpiece. It is therefore essential to use alternative methods to monitor the condition of the cutting tool rather than relying solely on the "senses" of an experienced workman.

There are numerous methods for automatically monitoring tool condition during a machining operation. These methods can be broadly classified into two main categories; direct methods and indirect methods. In direct methods, actual wear of the cutting tool is measured. In indirect methods, the effects of tool wear, such as variation in temperature, cutting forces, power, torque, etc. are measured. As a general rule, the indirect methods are better suited for in-process tool condition monitoring. Cutting force variation, as a measure of tool wear, is ideally suited for automated and numerical control machining, since cutting forces change with tool wear and force measuring devices can be easily incorporated into production machines.

Prior art force measuring systems measure the cutting force loads between two machine components. Prior art arrangements typically consist of one or more load cells or transducers placed between two machine components for detecting or measuring the forces acting at the interface between the two components. The corresponding output signal from the transducer is representative of the cutting forces generated between the tool and workpiece during the machining process. When the transducer output signal is inputed to appropriate signal conditioning equipment, an assessment of tool condition can be obtained.

One problem associated with these prior art force measuring systems is that the machine tool must be modified to incorporate the force measuring system. Such modifications can be costly to make. Further, due to the high cost of the equipment, many persons are hesitant to make the modifications needed to incorporate the prior art force measuring systems.

## SUMMARY AND OBJECTS OF THE INVENTION

The present invention provides a method and apparatus for monitoring cutting forces in a machine tool which requires no modification to the machine tool. The invention comprises a bolt transducer which can be mounted at any machine component interface which experiences cutting force loads from the machining process. The transducer assembly is mounted between the head of a bolt and one of the machine components secured by the bolt. The transducer assembly includes a force transducer, an upper shim, and a lower shim. The bolt preferably extends through the transducer assembly though such is not necessary. When preloaded during normal assembly of the machine components, the transducer will be able to measure increases or decreases in tensile load on the bolt caused by the machining process. The variation in bolt tensile load will be opposite in magnitude to the interface load between the two machine components. For example, an increase in the interface load between machine components will cause a corresponding decrease in bolt tensile load and vice versa. The transducer is able to accurately measure these variations in bolt tensile load which are representative of the cutting forces generated between the tool and workpiece. The very high sensitivity of piezoelectronic load cells make this transducer assembly an accurate, reliable, and effective means for measuring cutting forces. When the output signal is input to appropriate signal conditioning equipment, an assessment of tool condition can be obtained.

Accordingly, a primary object of the present invention is to provide a method and apparatus for monitoring tool condition which can be incorporated into existing machine tools without any modification to the machine tools.

Another object of the present invention is to provide a method and apparatus for monitoring tool condition which can be mounted on any bolt securing any two components together which experience cutting force loads.

A further object of the present invention is to provide a sensor assembly for monitoring tool condition that is capable of accurately measuring cutting forces associated with the tool.

Another object of the present invention is to provide a load sensing arrangement which will be sensitive to small changes in tensile load of a bolt.

Still a further object of the present invention is to provide a transducer mounting arrangement in which the inherent stiffness of the transducer has no effect on the overall stiffness of the machine at the transducer mounting location.

Other objects and advantages of the present invention will become apparent and obvious from a study of the following description and the accompanying drawings which are merely illustrative of such invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

**Figure 1** is a schematic illustration of a machine tool having the transducer assembly of the present invention mounted thereon.

**Figure 2** is a schematic illustration of the transducer assembly enclosed with a protective housing.

**Figure 3** is a schematic illustration of a second arrangement for the force transducer assembly.

**Figure 4** is a schematic illustration of a third arrangement for the force transducer assembly.

## DETAILED DESCRIPTION OF THE INVENTION

With further reference to the drawings, a machine tool is schematically shown in Fig. 1 and indicated generally by the numeral 10. The machine tool comprises a turret housing 12 mounted to a support member 24 by bolts 26. A turret disc 14 is rotatively mounted to the housing 12 and carries a detachable tool holder 16. Toolholder 16 is adapted to receive and hold a cutting tool 18. A workpiece holder 22 is disposed adjacent the tool holder 16 and is designed to receive and hold a workpiece 20. During a machining operation, the cutting tool 18 is brought into engagement with the workpiece 20.

During a machining operation, the cutting forces experienced by the cutting tool 18 are transmitted through the tool holder 16, turret disc 14 and turret housing 12 to the support member 24. The loads at the interface between any two of these components will vary as the cutting forces on the cutting tool 18 vary. The present invention provides an indirect measure of these cutting forces by measuring the effects of cutting force loads on the bolt 26 which connects the turret housing 12 and support member 24. In the embodiment shown, a force transducer assembly 30 is mounted on a bolt 26 securing the turret housing 12 to the support member 24. The force transducer assembly 30 measures the change in tensile load of the bolt 26 securing these two members together. The tensile load on the bolt 26 will vary in magnitude during the machining process. The variation in the tensile load on the bolt 26 will be opposite in magnitude to the cutting force load between the two machine components 12 and 24. For example, an increase in the interface load between the machine components 12 and

24 will cause a decrease in bolt tensile load, and vice versa. The transducer assembly monitors the variation in bolt tensile load to provide an indication of the cutting forces.

Referring now to Fig. 2, there is shown a schematic illustration of the force transducer assembly. The force transducer assembly 30 includes a piezoelectric load cell 32 which is mounted in force transmitting relationship between the head of the bolt 26 and the turret housing 12. Load cell could also be placed between a nut or stop and one of the machine components. The load cell 32 is sandwiched between two force distributing elements. In this embodiment, the force distributing elements consist of an upper shim 34 and lower shim 36. In a preferred embodiment of the invention, the load cell 32 and force-distributing elements 34 and 36 are ring-shaped and the bolt 26 passes through the center of the force transducer assembly 30. Other configurations where the load cell 32 is located in close proximity to the bolt are also possible as will be hereinafter described in detail.

In some applications, the load cell 32 will be mounted in a hostile environment on the machine. Sealing and protecting the load cell can be accomplished by enclosing the transducer assembly 30 in a water-tight housing 50 as shown in Fig. 2. Two screws 58 secure the water-tight housing 50 to the turret housing 12 in the figure. An adhesive sealant 56 can be used with the screws 58 or independently to secure the components together. The load cell's signal cable 48 can pass through a reinforced hose connected to an appropriate fitting 54 on the housing. Alternatively, the load cell 32 can be assembled into a self-contained and sealed shim.

Load cell 32 is preloaded during assembly of the machine components by tightening bolt 26 a predetermined amount. During a machining operation, variations in the cutting force will cause a corresponding increase or decrease in the cutting force loads at the interface between the two machine components. A resulting increase/decrease in the bolt's tensile load also occurs which is opposite in magnitude from that of the interface load between the two machine components. For example, an increase in the interface load causes a corresponding decrease in bolt tensile load and vice versa. The highly sensitive load cell 32 is able to accurately measure the variations in bolt tensile loads, and outputs a signal corresponding to the magnitude of the change. The signals produced by the load cell 32 are passed through a signal cable 48 to appropriate signal processing equipment which extracts information regarding the tool condition.

Referring now to Fig. 3, a second embodiment of the present invention is shown. In this embodiment, the force transducer assembly 30 includes a load cell 32 which is also mounted in force transmitting relation between the head of the bolt 26 and the turret housing 12. However, unlike the previous embodiment, the load cell 32 is disposed closely adjacent to one side of the bolt 26, rather than surrounding the bolt 26. The transducer assembly 30 includes two force distributing elements. In this embodiment, one of the force distributing elements comprises a shim 36. The upper force distributing element comprises a force transmitting lever 38. The force transmitting lever 38 includes a semi-circular fulcrum 40, a lever portion 44, and a through hole 42 disposed between the fulcrum 40 and the lever portion 44. The bolt 26 extends through the throughhole 42 and is tightened against the lever 38 so that the lever portion 44 presses down against the load cell 32.

The force transducer assembly 30 of the second embodiment works in the same manner as in the previous embodiment. When the cutting force load at the interface between the machine tool components increases, the tensile load on the bolt will decrease. The load cell 32 monitors the variations in the tensile load on the bolt. The output signal from the load cell 32 is transmitted to signal processing equipment to provide an indication of the cutting forces.

Referring now to Fig. 4, a third embodiment of the invention is shown. The force transducer assembly 30 of this embodiment is designed for use with two or more adjacent bolts 26 securing the machine components together. This embodiment uses a force distributing plate 46 as a force distributing member. Bolts 26 are extended through bolt holes in the plate 46 and secure the two machine components together. A load cell 32 is disposed in force-transmitting relation between the force distributing plate 46 and one of the machine components. The bolts 26 are then tightened to preload the cell 32. The force transducer assembly 30 of this embodiment operates in the same manner as previously described.

Based on the foregoing, it is apparent that the transducer assembly of the present invention can be used in virtually any machine tool without modification to the tool. The transducer assembly 30 simply mounts onto or in close proximity to an adjacent existing bolt 26. An existing bolt can be removed and replaced with a slightly longer bolt to accommodate the transducer assembly. Thus, the force transducer of the present invention is practical and can be readily incorporated into existing machine and cutting tool assemblies.

The present invention may, of course, be carried out in other specific ways than those herein set forth without departing from the spirit and essential characteristics of the invention. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

## CLAIMS

What Is Claimed Is:

1. A method of sensing and monitoring cutting forces on a cutting tool assembly having first and second machine components secured together by a bolt comprising the steps of:

(a) sensing the change in tensile load acting on the bolt caused by changes in cutting forces experienced by the cutting tool assembly during a machine operation; and

(b) monitoring the sensed changes in tensile load of the bolt to provide an indication of the cutting forces being experienced by the tool assembly.

2. In a tool assembly having two separate machine elements disposed adjacent to each other and connected by at least one threaded connector, a tool monitoring sensor system for sensing and monitoring cutting forces associated with the tool assembly comprising: a force transducer mounted in force transmitting relationship between the connector and one of the machine elements; and wherein the force transducer is held in compression by the connector joining the two machine elements together and is operative to sense changes in the tensile load of the connector in responses to changes in the load at the interface of the machine elements which result from changes in cutting forces experienced by the tool assembly such that the cutting forces associated with the tool assembly can be continuously sensed and monitored by effectively measuring the tensile load on the connector connecting the two machine elements together.

3. The tool monitoring sensor system of claim 2 wherein the connector connecting the two machine elements includes a stop and wherein the force transducer is movably held in compression between the stop and one of the machine elements.

4. The force transducer assembly of claim 2 wherein said force transducer has an opening formed therein and wherein said connector extends through the bolt opening in the force transducer.

5. The force transducer assembly of claim 4 wherein said force transducer has a ring-like configuration.

6. The force transducer assembly of claim 2 further including a force distributing member interposed between the connector and the force transducer.

7. The force transducer assembly of claim 6 wherein the force distributing member comprises a shim.

8. The force transducer assembly of claim 6 wherein the force distributing member comprises a force distributing plate interposed between two or more connectors and the force transducer.

9. The force transducer assembly of claim 6 wherein the force distributing member comprises a force transmitting lever including a fulcrum which bears against the machine element and a lever portion pressed into engagement with the load cell by said connector.

10. A method for measuring and monitoring cutting forces in a machine tool comprising:

(a) selecting first and second machine tool components in abutting relationship to one another which experience cutting force loads during a machining operation;

(b) securing said first and second machine tool components together with a threaded connector, such that said connector will experience changes in tensile load opposite in magnitude to the loads at the interface between the machine tool components as cutting force loads vary; and

(c) measuring said tensile load on said threaded connector to provide an indication of the cutting forces.

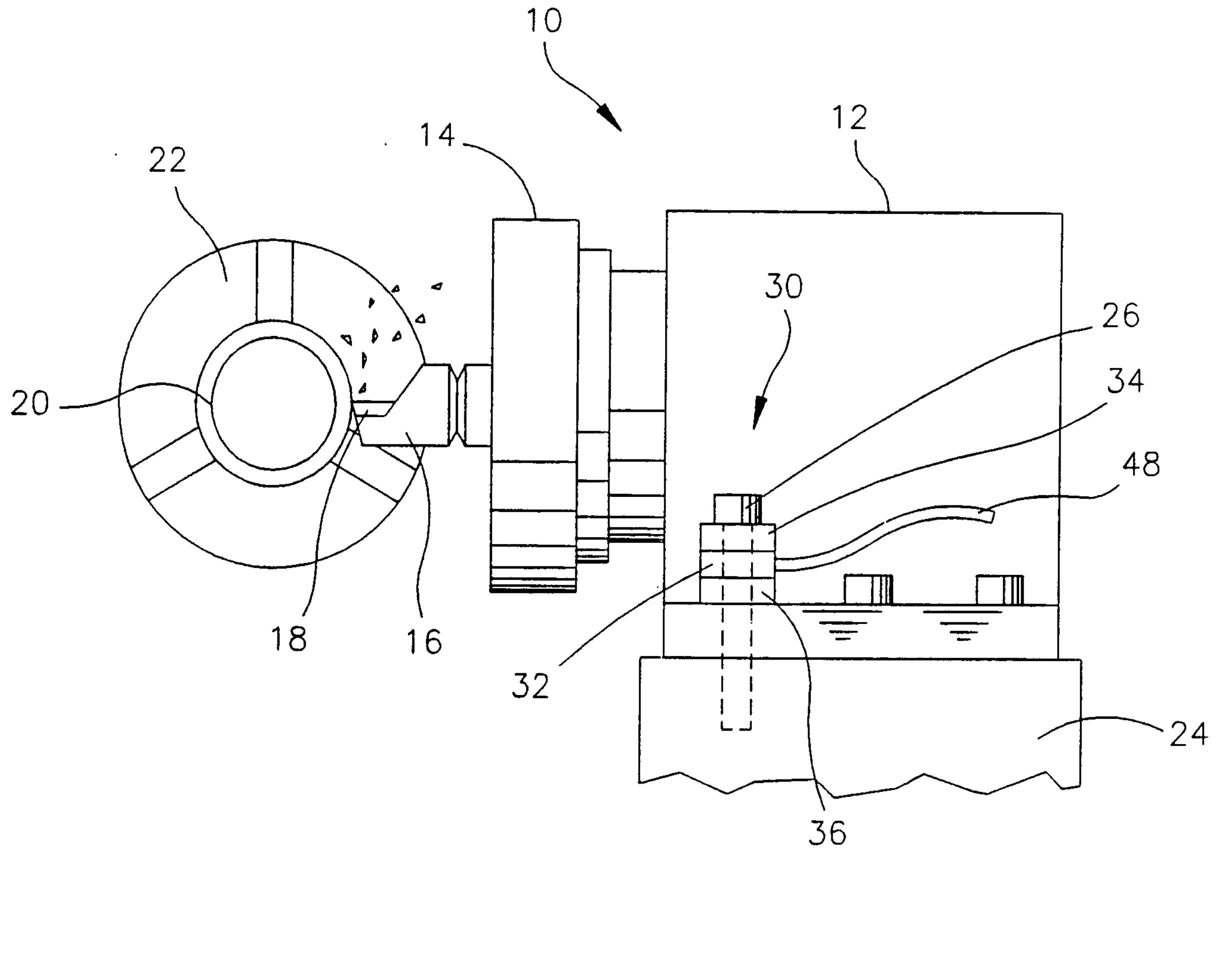


FIG. 1

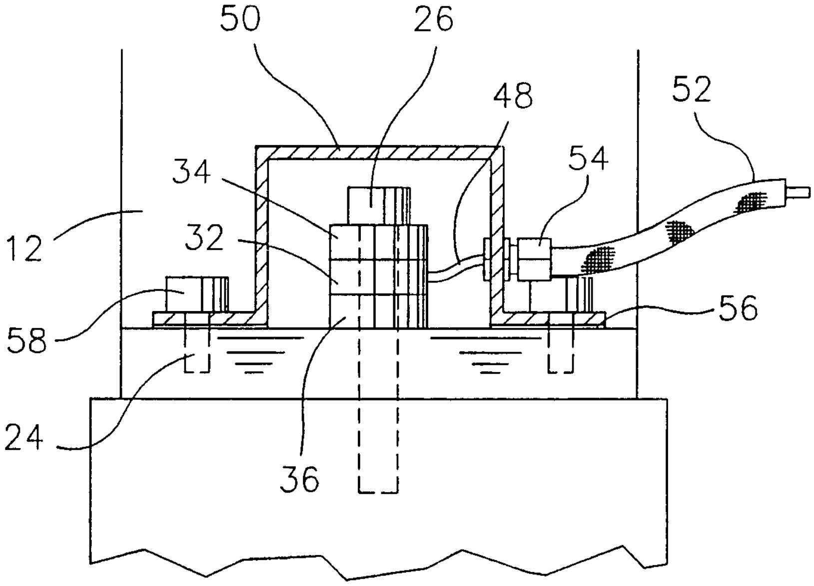


FIG. 2

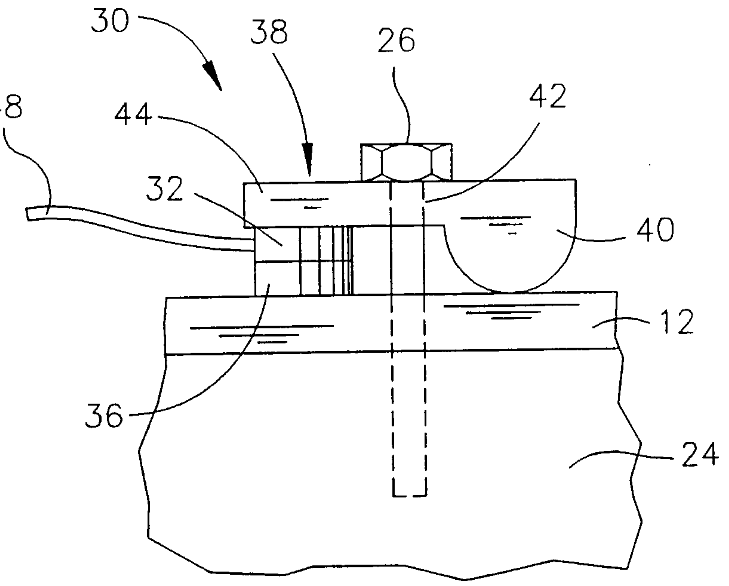


FIG. 3

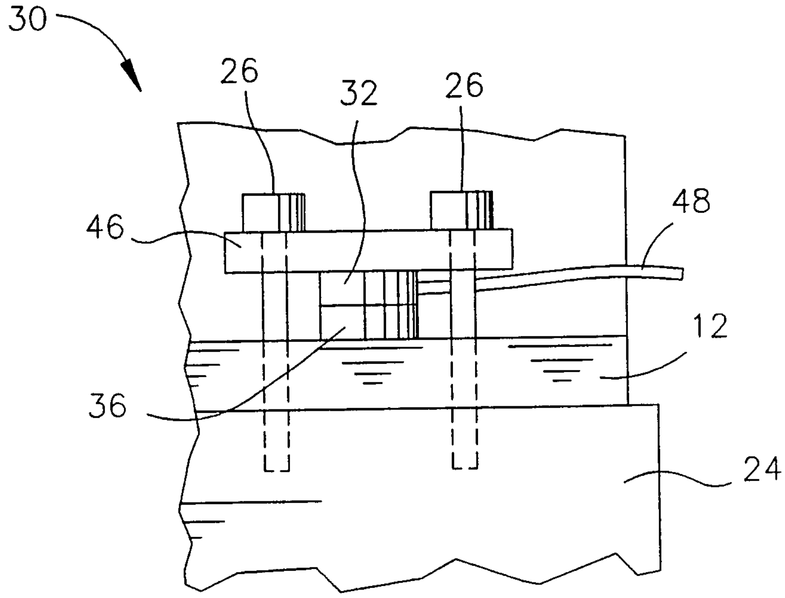


FIG. 4

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/US93/03983

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(5) :GOIL 5/16
US CL :73/862.06
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)

U.S. : 73/862.06
73/862.625, 862.642, 862.68 DIG. 4, 104, 115, 761

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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| Y | US, A, 3,153,974 (Canning) 27 OCTOBER 1964<br>See entire document. | 1, 2, 4, 5, 10 |
| Y | US, A, 3,461,715 (Stover III) 19 AUGUST 1969<br>See entire document. | 1, 2, 4-7, 10 |
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| Y | US, A, 3,495,704 (Kraus et al.) 23 MARCH 1976<br>See entire document. | 1, 2, 4, 5, 10 |
| Y | US, A, 3,948,141 (Shinjo) 06 APRIL 1976<br>See entire document. | 1, 2, 4, 5, 10 |

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

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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| X | US, A, 4,875,365 (Powell et al.) 24 OCTOBER 1989<br>See entire document. | 1-3, 6, 7, 10 |