Abstract: The present invention provides an integrated rotating dynamometer (100) for measurement of cutting force in milling or drilling process. Accordingly, the rotating dynamometer (100) includes: a) a tool holder spindle (110); b) a force sensing element (200); c) a bottom shaft module (120) detachably received a cutting tool (130) insert; said cutting tool (130) is being joined to the force sensing element (200) through the bottom shaft module (120); d) a strain gauge mounting module (220) mounted to a body (140) of the rotating dynamometer (100); wherein the tool holder spindle (110) has a shaft (112) through which the force sensing element (200) is connected thereto; wherein the body (140) works for wrapping coil of telemetry transmitter system for power supply and data transmitter; and wherein any forces that occur in the cutting tool (130) will be forwarded through the bottom shaft module (120), such that it will deform the force sensing element (200) and can be detected by the strain gauge mounted at the strain gauge mounting module (220).
before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))
INTEGRATED ROTATING DYNAMOMETER FOR MILLING OR DRILLING PROCESS

FIELD OF INVENTION

The present invention relates generally to a dynamometer, and more particularly to an integrated rotating dynamometer for measurement of cutting force in milling, drilling, or turning process.

BACKGROUND OF INVENTION

Nowadays, flexibility and re-configurability are the most significant challenges to machining process. In this regard, application of sensors system must have a sufficiently broad operating range to allow for various cutting tool sizes and workpiece configurations. Therefore, there has been interested in developing a force-sensing system built into the machine tool structure in order to allow for efficient re-configurability.

The cutting force measurement is an essential requirement in machining process. One of the most machining process variables related to the cutting performance is the cutting force that is generated by the cutting tool as it cut and shears the workpiece. Commonly, table dynamometers are used to measure cutting force in milling and drilling process, where a workpiece is mounted on top of the dynamometer which is clamped to a machine tool table. The principle of the commercial dynamometer is pressure detection using piezoelectric materials that are used in dynamometer construction as the main element and are converted to a proportional electric charge.
The cutting force is significant information for help understand the machining process, optimization, tool condition monitoring, tool design and others. Hence, various methods of cutting force measurement have been proposed by many researchers. Although there were several theoretical studies have been carried out on the cutting force measurement, there are found to be unsatisfactory due to the difficulty in installation and implementation such that they contain certain drawbacks that made them not become widely used.

In view of these and with the growing of the microsystems industry, it would be advantageous to provide an innovative integrated of rotating dynamometer that is constructed and fabricated to fulfil the requirement in measurement of cutting force for milling, drilling or turning process. Accordingly, the present invention provides an integrated rotating dynamometer for measurement of cutting force in a milling and/or drilling process. The developed integrated rotating dynamometer provides a simple, but an effective device for cutting force measurement; it also provides easy assembly with substantially low cost, and without compromising the existent of its performance.
SUMMARY OF THE INVENTION

The present invention relates to an integrated rotating dynamometer for measurement of cutting force in milling or drilling process. Accordingly, the rotating dynamometer includes: a) a tool holder spindle; b) a force sensing element; c) a bottom shaft module detachably received a cutting tool insert; said cutting tool is being joined to the force sensing element through the bottom shaft module; d) a strain gauge mounting module mounted to a body of the rotating dynamometer; wherein the tool holder spindle has a shaft through which the force sensing element is connected thereto; wherein the body works for wrapping coil of telemetry transmitter system for power supply and data transmitter; and wherein any forces that occur in the cutting tool will be forwarded through the bottom shaft module, such that it will deform the force sensing element and can be detected by the strain gauge mounted at the strain gauge mounting module.

In the preferred exemplary of the present invention, one end of the bottom shaft module is securely connected to the force sensing element and other end of the bottom shaft module detachably received the cutting tool insert.

By way of example but not limitation, the force sensing element is attached to the shaft of the tool holder spindle by a fastener. Similarly, the cutting tool is joined to the force sensing element through the bottom shaft module by other fasteners.

It will be appreciated that the strain gauge mounting module is accommodated within the body, and being covered by a top cover plate and bottom cover plate. By way of example and not by the way of limitation, the top and bottom plates are longitudinal tied by fasteners, and laterally tied by other suitable fasteners.
In the preferred exemplary, the force sensing element is preferably, but not limited to provide with predefined substantially L- or curve-shaped channels radially extended from its center axis. By way of example but not limitation, each channel preferably includes at least two strain gauges which are subject to tensile stress and also subject to compressive stress.

It will be appreciated that half Wheatstone bridge circuits are to be used for all channels of signal which is existed and being mounted in the strain gauge module. Accordingly, the main cutting force, $F_c$ is detected by strain gauge at point A of the channel of the force sensing element; thrust force, $F_t$ is detected by strain gauge at point B of the channel of the force sensing element; and perpendicular cutting force, $F_{cN}$ is detected by strain gauge at point C of the channel of the force sensing element.

The present invention consists of several novel features and a combination of parts hereinafter fully described and illustrated in the accompanying description and drawings, it being understood that various changes in the details may be made without departing from the scope of the invention or sacrificing any of the advantages of the present invention.
BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be fully understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, wherein:

**FIG. 1a** shows a full assembly view in perspective of an integrated rotating dynamometer for measurement of cutting force in accordance with preferred exemplary of present invention;

**FIG. 1b** shows a partially cross-sectional view in perspective of the integrated rotating dynamometer for measurement of cutting force of **FIG. 1a**;

**FIG. 2** is an exploded view in perspective of the integrated rotating dynamometer for measurement of cutting force according to preferred exemplary of the present invention;

**FIG. 3** shows an enlarged view of a force sensing element of the integrated rotating dynamometer according to preferred exemplary of the present invention.

**FIGS. 4a to 4c** show a calibration curve for main cutting force $F_c$, thrust force $F_t$, and perpendicular cutting force $F_{CN}$ respectively, at the force sensing element;

**FIGS. 5a to 5c**, show frequency response functions for main cutting force $F_c$ direction, thrust force $F_t$ direction, and perpendicular cutting force $F_{CN}$ direction.
DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to an integrated rotating dynamometer for measurement of cutting force in milling or drilling process. Hereinafter, this specification will describe the present invention according to the preferred exemplary, methods and/or embodiments of the present invention. However, it is to be understood that limiting the description to the preferred exemplary of the invention is merely to facilitate discussion of the present invention and it is envisioned that those skilled in the art may devise various modifications and equivalents without departing from the scope of the appended claims.

In accordance with the preferred exemplary of the present invention, the integrated rotating dynamometer generally provided with strain gauges that are to be mounted in the newly designed force sensing element. The force sensing element will then be placed in a rotating tool holder for a milling, drilling or turning process. In the preferred exemplary, the force sensing element is preferably, but not limited, to be configured in form of a symmetrical cross beam type with four arms that shaped a rectangular parallelepiped.

It should be noted that this integrated rotating dynamometer is intended to be used in a rotating spindle, such as in the milling or drilling process. The present invention also provides a data conditioning system and an inductive telemetry transmitter unit which are incorporated into a modified tool holder in order to collect and transmit the cutting force signal to the data acquisition system.

Accordingly, the integrated rotating dynamometer has been subjected to series of tests to determine its static and dynamic characteristics. The results show that the integrated
of rotating dynamometer and tool holder is reliable to measure the cutting force in milling or drilling process.

The integrated rotating dynamometer for measurement of cutting force in milling or drilling process according to the preferred exemplary of the present invention will now be described in more detail with reference to accompanying FIGS. 1a to 5c, either individually or in any combination thereof.

Referring to FIGS. 1a to 2, illustrated therein is a rotating dynamometer (100) according to the preferred exemplary of the present invention. It should be noted that the rotating dynamometer (100) is integrated in a tool holder spindle (110) for machining process, such as for example, but not limited, to a milling or drilling process. In the preferred exemplary, the rotating dynamometer (100) generally includes a tool holder spindle (110), a force sensing element (200), a bottom shaft module (120) detachably received a cutting tool (130) insert, and a strain gauge mounting module (220) rotatably mounted to a body (140) of the rotating dynamometer (100).

Accordingly, the tool holder spindle (110) has a shaft (112) through which the force sensing element (200) is securely connected to the shaft (112) of the tool holder spindle (110). By way of example but not limitation, the force sensing element (200) is attached to the shaft (112) of the tool holder spindle (110) by, for example, a M8 fastener (202). It will be appreciated that one end of the bottom shaft module (120) is securely connected to the force sensing element (200), and other end of the bottom shaft module (120) detachably received the cutting tool (130) insert. Accordingly, the cutting tool (130) is being joined to the force sensing element (200) through the bottom shaft module (120).
Preferably, but not limiting, said cutting tool (130) is joined to the force sensing element (200) through the bottom shaft module (120) by, for example, M6 fasteners (122).

In the preferred embodiment, the strain gauge mounting module (220) is being accommodated within the body (140). Said strain gauge mounting module (220) is being covered by a top cover plate (142) and bottom cover plate (144) of the body (140). It will be appreciated that the body (140) is mounted outside the top cover plate (142) and the bottom cover plates (144), and then joined to the shaft (112) of the tool holder spindle (110). By way of example but not limitation, the top and bottom plates (142 and 144), are preferably longitudinal tied by M3 fasteners or screws (146), and laterally tied by suitable fasteners or screws (148).

By way of example but not limitation, the body (140) facilitates to serve, or to work for wrapping the coil of telemetry transmitter system (rotor). Accordingly, said body (140) is works for wrapping the coil of telemetry transmitter system that consist coil for power supply and data transmitter. It should be noted that any forces that occur in the cutting tool (130) will be forwarded through the bottom shaft module (120), such that it will deform the force sensing element (200) and can be detected by the strain gauge mounted at the strain gauge mounting module (220).

By way of example but not limitation, half Wheatstone bridge circuits are to be used for all channels (210) of signal which is existed and being mounted in the strain gauge module (220). It should be noted that the force sensing element (200) is preferably, but not limiting, to provide with predefined substantially L- or curve- shaped channels (210) radially extended from its center axis as shown in FIG. 3. It will be appreciated that each channel (210) is preferably, but not limited to, include two strain gauges (not shown)
which are subject to tensile stress and also subject to compressive stress. Accordingly, main cutting force, $F_C$ is detected by strain gauge at point A; thrust force, $F_T$ is detected by strain gauge at point B; and perpendicular cutting force, $F_{CN}$ is detected by strain gauge at point C.

Sensor System

In the preferred exemplary of the present invention, the force sensing elements (200) based on strain gauges have a so-called spring element. When an external load is applied to force sensing element (200), stress and strain within the surface of material change. Strain gauge will be converted the strain into voltage signals that imply the applied force. When the strain gauges mounted onto the force sensing element, they will undergo the changes of the strain value or resistance that reflect the change of stress due to applied loading or forces. The change in resistance of a strain gauge is normally expressed in terms of an empirically determined parameter called the gauge factor, $GF$. It is also as a fundamental parameter about the sensitivity to strain and can be written as:

$$GF = \frac{AR/R}{AL/L} - \frac{AR/R}{\epsilon}$$

where $R$ is the original resistance of the strain gauge, $L$ is the original length, and $\epsilon$ is the strain detected from the strain gauge.

In order to achieve maximum sensitivity, the location of the point where the strain gauges are mounted is essential. There are three orientations of strain gauge locations for measuring main cutting force $F_C$, thrust force $F_T$ and perpendicular cutting force $F_{CN}$ as shown in FIG. 3. As mentioned earlier, to detect the change of the strain values, half...
Wheatstone bridge circuits are used for all channels (210) of signal. Each channel (210) includes two strain gauges which are subject to tensile stress and also subject to compressive stress. Said main cutting force, $F_C$ is detected by strain gauge at point A; thrust force, $F_T$ is detected by strain gauge at point B; and perpendicular cutting force, $F_{CN}$ is detected by strain gauge at point C.

By way of example but not limitation, signals coming from the force sensing element (200) in the rotating dynamometer (100) are amplified by acquisition module for strain gauge, for example but not limited to, MT23-STG, and analogue signals are then to be converted to a digital output.

By using a transmitter module, for example but not limited to, MT32-IND-Tx-45MHz-2560k, the signals transmit within frequency 45 MHz and transmission rate up to 2560 kb/s. It will be appreciated that sensor and transmitter modules are mounted in the space that is integrated with the standard tool holder spindle (110). A telemetry receiver, for example but not limited to, MT32-DEC8 and data logger, for example, DT9836 are being used to collect the signals. The acquisition, visualization and processing of the collected signal is then performed, for example but not limiting, via MATLAB 2012.

20 **Calibration of Rotating Dynamometer**

a) **Static calibration**

Calibration is a process to determine of the relationship between the input and output data. The static calibration was done to investigate the performance of force transducer after designed and constructed. The loads were applied up to 2000 N for the main and perpendicular cutting force ($F_C$ and $F_{CN}$) and 3000 N for thrust force ($F_T$) with 100 N intervals, and the output voltage values in millivolt were averaged and recorded for each
load intervals. Then, calibration curves were obtained to convert the output voltage readings into forces values. FIGS. 4a to 4c show a calibration curve for main cutting force $F_c$, thrust force $F_t$, and perpendicular cutting force $F_cN$ respectively. The measurements were repeated five times to verify the consistency and the average values recorded in curves.

The effect of applied force in one direction on the other force components was examined and minor fluctuations were observed. These effects were small enough to be ignored. It can be observed from the figures that the correlation coefficients were 0.994, 0.995 and 0.999 respectively, and the forces sensitivity were $4.98 \times 10^{-4} \text{ mV/N}$, $4.23 \times 10^{-4} \text{ mV/N}$ and $8.53 \times 10^{-4} \text{ mV/N}$.

**b) Dynamic Calibration**

When the rotating dynamometer (100) is mounted on the machine, the cutting forces occur are not static, the system response of dynamic excitations should have been taken into consideration. Dynamic response is affected by the natural frequencies of the rotating dynamometer. Natural frequency must be higher than the frequency of exciting vibration during machining process in order to ensure the recorded cutting force signal is not influenced by the dynamic response of the rotating dynamometer (100). It will be appreciated that the natural frequencies of the rotating dynamometer (100) are determined by frequency response function that is obtained by means of experimental modal analysis. By way of example but not limitation, the rotating dynamometer (100) is excited by using a modal impact hammer Endevco type 3012, and one accelerometer (Endevco 751-100) is connected to the component of dynamometer. The signals are acquired by pulse analyzer and modal analysis is performed in order to derive the frequency response function of the rotating dynamometer for three directions of force.
measurement. As shown in FIGS. 5a to 5c, frequency response functions for main cutting force $F_c$ direction, thrust force $F_t$ direction, and perpendicular cutting force $F_{CN}$ direction. It can be described that the natural frequency of the rotating dynamometer is not much different from the design calculation that are approximately 980.7 Hz, 1959.2 Hz and 470.5 Hz.

It is to be understood that both the set forth examples and detailed description are exemplary and explanatory only, and are not restrictive of the invention. As such, the set forth examples and detailed description, including methodology, configurations, shapes, materials and its contents or any other variable parameters and methods as described above should not be construed as limiting, but as the best mode contemplated by the inventor for carrying out the invention.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the principle and scope of the invention, and all such modifications as would obvious to one skilled in the art intended to be included within the scope of following claims.
CLAIMS

1. A rotating dynamometer for measurement of cutting force, the rotating dynamometer (100) includes:
   a) a tool holder spindle (110);
   b) a force sensing element (200);
   c) a bottom shaft module (120) detachably received a cutting tool (130) insert;
      said cutting tool (130) is being joined to the force sensing element (200) through the bottom shaft module (120);
   d) a strain gauge mounting module (220) mounted to a body (140) of the rotating dynamometer (100);

   wherein the tool holder spindle (110) has a shaft (112) through which the force sensing element (200) is connected thereto;
   wherein the body (140) works for wrapping coil of telemetry transmitter system for power supply and data transmitter; and
   wherein any forces that occur in the cutting tool (130) will be forwarded through the bottom shaft module (120), such that it will deform the force sensing element (200) and can be detected by the strain gauge mounted at the strain gauge mounting module (220).

2. The rotating dynamometer according to Claim 1, wherein the one end of the bottom shaft module (120) is securely connected to the force sensing element (200) and other end of the bottom shaft module (120) detachably received the cutting tool (130) insert.
3. The rotating dynamometer according to Claim 2, wherein the force sensing element (200) is attached to the shaft (112) of the tool holder spindle (110) by a fastener (202).

4. The rotating dynamometer according to Claim 2, wherein the cutting tool (130) is joined to the force sensing element (200) through the bottom shaft module (120) by fasteners (122).

5. The rotating dynamometer according to Claim 1, wherein the strain gauge mounting module (220) is accommodated within the body (140), and being covered by a top cover plate (142) and bottom cover plate (144).

6. The rotating dynamometer according to Claim 5, wherein the top and bottom plates (142 and 144) are longitudinal tied by fasteners (146), and laterally tied by suitable fasteners (148).

7. The rotating dynamometer according to Claim 1, wherein the force sensing element (200) is provided with predefined substantially L- or curve-shaped channels (210) radially extended from its center axis.

8. The rotating dynamometer according to Claim 7, wherein each channel (210) includes at least two strain gauges which are subject to tensile stress and also subject to compressive stress.
9. The rotating dynamometer according to Claim 8, wherein half Wheatstone bridge circuits are to be used for all channels (210) of signal which is existed and being mounted in the strain gauge module (220).

10. The rotating dynamometer according to Claim 9, wherein main cutting force, $F_c$ is detected by strain gauge at point A of the channel (210) of the force sensing element (200).

11. The rotating dynamometer according to Claim 9, wherein thrust force, $F_t$ is detected by strain gauge at point B of the channel (210) of the force sensing element (200).

12. The rotating dynamometer according to Claim 9, wherein perpendicular cutting force, $F_{CN}$ is detected by strain gauge at point C of the channel (210) of the force sensing element (200).
FIG. 3

FIG. 4a
FIG. 4b

\[ y = 0.000423x + 0.00365 \]

FIG. 4c

\[ y = 0.000853x - 0.013 \]
FIG. 5a

FIG. 5b
FIG. 5c
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

Int.Cl. G01L5 / 00 (2006.01) ; B23Q1 7/09 (2006.01) ; G01L5 / 16 (2006.01)

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)

Int.Cl. G01L / 00·5/ 2 8 , B23Q1 7/09

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

- Published examined utility model applications of Japan 1992-1996
- Published unexamined utility model applications of Japan 1971-2015
- Published registered utility model specifications of Japan 1994-2015

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

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>A</td>
<td>US 2010/0145496 A1 (INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE) 2010.06.10, the whole document &amp; TW 201021961 A</td>
<td>1-12</td>
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☑ Additional documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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  - "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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Date of the actual completion of the international search: 20.11.2015
Date of mailing of the international search report: 01.12.2015

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Form PCT/ISA/210 (second sheet) (July 2009)
### DOCUMENTS CONSIDERED TO BE RELEVANT

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