POWER CONSUMPTION BASED ONLINE CONDITION MONITORING IN MILLING MACHINE

Serg, R.; Aruväli, T.; Otto, T.

Abstract: Nowadays situation monitoring of production machinery is key factor in achieving production efficiency. Recent production equipment has often several sensors and monitoring facilities built-in but mostly for condition monitoring of a single unit. Mostly gathered data is only available to machine manufacturer. System for online machine monitoring using heterogeneous WSN has been proposed previously. Several methods of lathe condition monitoring have been researched. Currently easily deployable online condition monitoring system based on measurements of power consumption of milling machine is proposed and its efficiency researched.

Key words: manufacturing, condition monitoring, e-diagnostics, wsn

1. INTRODUCTION

High utilization of production machinery is one of the key performance factors for achieving high production efficiency. Possible unintentional mistakes in production planning or operating the production machine could lead to inefficient use of assets, poor quality of the products, interruptions in production process and even costly unplanned repairs. Older production equipment has usually very little or no monitoring systems installed. Machines itself are usually massive and in relatively good condition and can be used in production for some at least some years to come. Adding condition monitoring system to existing machinery adds additional value to the equipment and helps the users to increase efficiency.

Common challenge during extending existing equipment is the cost of the monitoring equipment and the complexity of the installation. Usage of WSN (Wireless Sensor Network) nodes allows keeping additional cabling minimal and cost for equipment at reasonable level. WSN nodes can be powered by batteries or mains electric net as manufacturing equipment is usually situated close to power connections. In case of extreme radio interference some nodes can be configured as routers to amplify transmission.

Monitoring of single manufacturing unit is advantageous indeed, but same concept can be extended to whole shop floor or even larger entity. Proposed data acquisition concept can be used in wider heterogeneous sensor network. Further usage of the recorder data for planning or interfacing it to ERP (Enterprise Resource Planning) systems is out of the scope of current paper. This paper will describe easily deployable online condition
monitoring system for milling machine based on its power consumption.

2. CURRENT STATUS

Most of new production machines are equipped with various sensors and systems to monitor their status. Unfortunately the monitoring systems serve usually mostly the interests of equipment manufacturers to assist them to identify faults in normal operation. User access to gathered monitoring data is usually very limited. On another side there is great interest in the users of the equipment to optimize the usage of the machinery and minimize downtime. Also, lot of manufacturing equipment is already in use and has still working resource available, but is lacking any monitoring equipment. Various solutions for improving the situation have been proposed. One could tell the operator to manually record the status of the machine writing it down to either paper or electronic ledger. Simple traffic light like system could be installed on machinery. The disadvantage of both described examples is human factor involved in the process and local availability of the gathered data.

3. PROBLEM DESCRIPTION

Situation awareness is often modeled in layers. Widely accepted situation awareness model for humans consists of 3 layers: perception, comprehension and projection. We will extend the same model to artificial systems. On perception layer some detectable physical phenomena is measured by suitable sensor and low-level understanding of the situation is established. Based on perception higher level of situation information is built – comprehension. “Better” understanding of the situation that usually takes into account wider information (for example from other sensors or sources). Highest level of situation awareness (in current model) is projection that describes possible future situation of the entity. In current paper perception and partly comprehension levels of situation awareness are discussed. Extending the same situation awareness model to machine industry one could say that single machine condition monitoring and situation detection can be seen as perception.

4. PRIOR WORK

Sensors are often used in machine tools to detect physical parameters and to evaluate moving components condition based on gathered data [1]. WSN (Wireless Sensor Network) [2] based measurement system has been developed and described previously [3]. Several tests involving temperature [4] and vibration [5] measurements and result analysis have been made on lathe to detect working modes. Measured physical parameters can be also used for machine tool utilization monitoring [6]. Furthermore, digital object memory integrated surface roughness detection and storage methodology is introduced to use the monitoring data all over product life cycle [7].

Current monitoring in machine tools is researched mainly in condition monitoring purposes. It is used mainly to evaluate motor condition [8], but also for bearing damage detection [9].

5. DESCRIPTION OF APPLICATION

Milling machine Dyna Mechtronics EM3116 installed in TUT mechanic lab
was used for testing. Power consumption of the machine was measured with specially developed current sensor. Current sensor is designed so, that it can be easily connected by receptacle and plug just on the line of main power input of the milling machine. No additional cabling is needed as data connection is performed by NI (National Instruments) WSN solution. WSN3202 node with stock firmware, 9220 WSN gateway and specially designed software running in LabVIEW environment on a dedicated PC were used for data acquisition. Special RDBMS (Relational Database Management System) PostgreSQL 9.1 has been set up for storing data. Data communication between data producer and storage is done over TCP/IP protocol, so database server installation site is limited only by availability of internet connection. Usage on another layer in data storage (database server) enables the use of heterogeneous sensor network – sensors can be of different type. If the sensor can communicate and write data to database, then it is suitable to be used with the system. Also, getting all data from different sensors together into one database makes it easier to deduct conclusions based on several different sensors measurement results. On the same time RDBMS handles the concurrent data access and provides options for data validation, manipulation, compacting and time stamping.

6. CONDUCTED TESTS

Milling machine Dyna Mechtronics EM3116 was used for tests. Two different current measurement sensors, sensor 1 with measurement range of 32 A and sensor 2 with measurement range 16 A, both with WSN based data communication were connected to the power line of the milling machine. Data from both sensors were gathered by special application, developed in NI LabVIEW environment, and saved to cloud server database with time stamps into two separate data tables (Fig. 1).

![Data collection scheme](image)

Fig. 1. Data collection scheme.

Two types of materials were used in tests: steel S355J2 and aluminum alloy 6082T6. Table 1 describes the setup for conducted tests.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Material used</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>Reference measurements: machine and spindle on/off</td>
</tr>
<tr>
<td>2</td>
<td>S355J2</td>
<td>Milling of steel at low feed rate</td>
</tr>
<tr>
<td>3</td>
<td>S355J2</td>
<td>Milling of steel at higher feed rate</td>
</tr>
<tr>
<td>4</td>
<td>S355J2</td>
<td>Forming the material</td>
</tr>
<tr>
<td>5</td>
<td>6082T6</td>
<td>Milling of aluminium at low feed rate</td>
</tr>
<tr>
<td>6</td>
<td>6082T6</td>
<td>Milling of aluminium at higher feed rate</td>
</tr>
<tr>
<td>7</td>
<td>6082T6</td>
<td>Forming the material</td>
</tr>
</tbody>
</table>

Table 1. Test parameters
Following milling program was composed:
N010 G21 G91; (set units mm, incremental movement)
N020 M03; (start spindle)
N030 F60; (set feed 60mm/min)
N040 M73 N3; (start program loop, execute 3 times)
N050 G01 Z-1,5; (move to cut depth)
N060 G01 X-95; (cut towards -X)
N070 G01 Z1; (rise tool from cut plane)
N080 G01 X96; (return to cutting start X)
N090 G01 Z-1; (lower tool to cut plane)
N100 M74; (program loop end)
N110 Z4,5; (take tool to initial Z plane)
N120 M02; (program end)

During tests 3, 4, 6 and 7 feed rate was increased to 90 mm/min and program row N030 was altered correspondingly.

7. RESULTS

The aim purpose of test 1 was to identify events of switching on/off the machine and spindle.
Current consumption is presented in fig. 2.

Event of switching on the machine can be seen at about 50 sec from start of test and switching on the spindle at about 180 sec from the start of the test.

Tests 2, 3, 4 and 5 showed similar pattern in current consumption. Most visible result can be seen in test 3 (Fig. 3). Least visible result was found during test 5 (Fig. 4).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling machine off</td>
<td>0</td>
</tr>
<tr>
<td>Milling machine on</td>
<td>0.7</td>
</tr>
<tr>
<td>Spindle on</td>
<td>3.2</td>
</tr>
<tr>
<td>Actual milling in test 2</td>
<td>3.4</td>
</tr>
<tr>
<td>Actual milling in test 3</td>
<td>3.5</td>
</tr>
<tr>
<td>Actual milling in test 5</td>
<td>3.3</td>
</tr>
<tr>
<td>Actual milling in test 6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table 2. Current consumption in different conditions are summarized in table 2.

![Fig. 2. Current consumption in different milling machine status: switched off, stand still and spindle turning.](image)

![Fig. 3. Current consumption in test 3.](image)

![Fig. 4. Current consumption in test 5.](image)
cutting conditions.

Measurements show that it is possible to detect milling machine on and spindle on conditions. Setting detection levels to 0.5 A and 3 A correspondingly the conditions of the machine can be deducted by the current consumption reliably. Equipment with higher accuracy is needed to detect actual milling process duration reliably. Analysis shows that whole milling program for test 3 consumed 0.26 kWh of electricity. Total power consumption can be reduced by at least 30% with increasing return movement speed of the tool or turning off the spindle during return movements.

8. CONCLUSIONS

Test results show that proposed solution is able to monitor milling machine utilization by measuring it is current consumption. In addition, switching on the machine and spindle can be detected reliably. Actual milling operation detection is highly dependable on the milling operation specifics and requires higher accuracy equipment for reliable condition detection.

9. REFERENCES


7. ADDITIONAL DATA ABOUT AUTHORS

Risto Serg, Research Laboratory for Proactive Technologies, Dep of Computer Control, risto.serg@ttu.ee
Tanel Aruväli, Dep. of Machinery, tanel.aruvali@student.ttu.ee
Tauno Otto, Dep. of Machinery, tauno.otto@ttu.ee
All authors are with Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia.