Remote maintenance and fault analysis system for custom-made machine

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Abstract: In the special machines and custom made machine industry, machine manufacturers have to deal with maintenance services in spread market, while individualization of customer demands increases complexity to maintenance services. That is the case in stone cutting machines manufacturing business, where maintenance is a critical factor because of the high customization of each machine and because of the variety and difference of the working conditions for similar machines. Stone mechanic characteristics or saw blade tool behaviour affect the process performance, which sometimes becomes a maintenance issue. Other factors as machines remote placements as well as user technology skills have to be taken into account. Remote maintenance based on remote monitoring and analysis and on realistic simulation helps in avoiding cost and frequent “local” maintenance services in this industry. However, both have to be as much realistic as possible to be able of getting useful information. The paper presents a control-monitoring-simulation architecture built around the use of “custom-made” machines models working with the actual “custom-made” control system. The paper describes how, with this architecture, efficient analysis and machine intervention may be achieved for stone cutting saw blade machines.

Keywords: Tele-maintenance; remote servicing; simulation; monitoring; machining.

1. INTRODUCTION

For stone construction parts, circular sawblades are the most popular cutting mechanism. Saw stone cutting machines may be complex, with 5 or more axis (Fig.1) to be able to machine complex construction stone parts, such as mouldings, columns, balusters, etc. Although saw blade stone cutting machines are similar (Brook, 2002), customer needs vary from one to each other, so the same machine manufacturer company might face a great deal product variety to produce, in terms of mechanical design but also in terms of control system implementation (Garrido, Marin, Armesto and Saez, 2009).

In these scenarios of customers distributed more and more widely, with custom-made complex machines, process conditions changes from one shop-floor customer to other, and low technical support from shop floors, remote-services (tele-services) (Iung, 2003) for maintenance and shop-floor machining process simulations is the solution for the problem of how to offer clients an efficient service to frequent assistance requests.

In exploring more efficient maintenance and service support, the approaches of collaborative maintenance, remote maintenance, and integration of production with maintenance, have evolved into a new phenomenon called e-maintenance to meet the needs of future e-world (Ucar and Qiu, 2005). E-maintenance is an Internet based proactive maintenance technology, which consists of remote real-time evaluation of performance degradation on assets such as equipment, products, and process. Through e-monitoring, e-diagnosis and e-prognosis, remote manufacturers and customers are supported and ensured of production machine performance and quality of processes (Han and Yang, 2006).

Fig. 1. Stone cutting saw blade 5 axis machine.

There have already been many experiences and research in remote maintenance services for machines (Iung, 2002), e-maintenance platforms for spread processes (Ucar and Qiu, 2007), intelligent prediction tools for proactive maintenance (Lee, 2006) (Garcia, Sanz-Bobi and Pico, 2006) and continuous degradation monitoring etc. Research in machine conditions monitoring helps in the pro-maintenance, and collaborative platforms have been developed to implement e-maintenance policy, plus new technologies and standards support machine control devices remote data access (MTConnect, 2007) (Ota and Wright, 2006).
However, main maintenance requirements for stone processing CNC machines manufacturers, shared by other small/medium “special machine” manufacturers in other industries, are not a continuous monitoring capability, an automatic proactive-maintenance, or collaborative maintenance and analysis platforms. But they are flexible and fast to set up for monitoring and analysis systems, with the ability of remotely experience (simulate) new machine operations (new “control systems kernels”, new “user or part programs”) with the intention of avoiding moving specialist to the machine site.

With this objective and within these scenarios, the paper presents a development/monitor/simulation architecture system developed for saw blade stone cutting machines control systems. The main feature of the system is that the actual machines control system (hardware configuration and software) drives the simulation response. This monitoring and simulation platform has an almost immediate set-up phase. Remote monitoring would allow the analyses of the machine processes with different configurations and machining conditions, and without almost any help from the shop-floor. Simulation supports the “local” machine development process, but also the machine control system maintenance and evolution.

Next section will review remote data monitoring and simulation for standard and custom-made machines. Section three will describe the principles, architecture and main elements of the system. Finally, section four is an e-maintenance experience example performed with the system.

2. REMOTE MONITOTRING AND SIMULATION

Supervisory system can be defined as a system that integrates and coordinates individual process monitoring and control modules such that a globally optimal machining solution could be delivered real-time for desired quality and maximum productivity.

Openness of CNCs and servo drives will easy use of process monitoring and control applications (Wosnik, Ckramer, Seling and Klemm, 2006). Industrial field-buses as Profibus and Sercos make available running and configuration data of from field devices to the processes controllers (PLC’s). With, standard controller data access protocols such as OPC (OLE for Process Control), PLC may be integrated with higher level information processes and provides on-line access to controller internal data (Dedinak, Wögerer, Haslinger and Hadinger, 2005) etc. New open communication standard such as MTConnect will allow devices, equipment, and systems to output data in an understandable format that can be read by any other device using the same standard format to read the data (MTConnect, 2007).

All these systems are “communication mechanisms” providing data access and interoperability. But finally, data recorded by these systems have to be related to other information to analyse it effects on the production process. The analysis of the data coming from the shop-floor needs also the knowledge of the remote process and environment. This is documented by the “part program” (“user program”).

Depending on the technology, it may be described by a standard specification (as for instance, G&M codes (ISO 6983, 1982) or by the new STEP-NC standard (ISO 14669, 2003) (ISO 10303-238, 2007) (Xu and Newman, 2006) which are interpreted and executed by the CNC controller. There are several machine tools and robots simulation systems as VNC, VERICUT, Machine Tool Builder and Synchronization Manager, etc., with the main focus of representing CNC machine tool resources and enable an NC simulation for collision free toolpath with an optimal sequence of operations to reduce the machining cycle. New machine models as the Unified Manufacturing Resource Data Model UMRM are being developed as a standard representation of machine tool and auxiliary devices to allow the exchange of the knowledge of the machine tool “mechanic” functionality (Vichare, Nassehi, Kumar and Newman, 2008).

But finally, simulation systems work with standard specification of the “part program” (G&M or STEP-NC) to animate the elements defined in the machine models (standard or not). There is a basic assumption that control systems works properly. There is no doubt about the correct behaviour of the controller and the machine, and the simulation is rather about the “user program”, in order to detect errors, potential collisions, or areas of inefficiency, and enables NC programmers to reduce prove-outs, virtually eliminate errors, and optimize NC “user” programs.

However, this is not the case when dialling with customized machines where the “control kernel” may change from one implementation to another. In the “special machines” sector, or sometimes in others as the “stone processing” machines one, both machine mechanical structure and “control system kernel” may be highly customized and be different in each machine implementation. The same machine mechanic configuration may produce one effect with different control system (control software and control hardware parametrization), and the control system itself is dependent of the machine mechanical behaviour. Therefore, same “user or part CAM program” may produce different results depending on the “control system” (element 1 in Fig. 2); and same couple of program and control system may produce different effects on different machines configurations (element 2 of Fig. 2): for instance, it may have different effects in the same machine but with different servos configuration.

Fig. 2. Models and actual data for process analysis.
3. REMOTE MAINTENANCE

Fig. 3 shows the control/monitoring/simulation architecture developed for CNC stone cutting machines, where same systems (hardware and software) are used for different development/maintenance activities (for control, for simulation or for monitoring). Also, Fig. 3 illustrates how same machine model is used for simulation and for monitoring. Next subsections will introduce the elements of this architecture.

![Fig. 3. Control/Monitoring/Simulation architecture.](image)

### 3.1 Machine Model

Automatic saw blade cutting machines for construction parts are very similar, despite the fact there are many machine manufacturers in many different regions, and despite the fact each manufacturer machine is equipped with particular solutions, special options and custom functionalities. Machines do vary in terms of mechanical configuration and in terms of control. Simpler machines make single or repetitive cuts, and some are equipped with several blades or several diamond wires to make more than one cut at a time. Other machines are designed and automated to be capable of performing complex tasks.

Some machines have an additional axis to rotate the stock and hence enable turned parts (revolution parts and indexed parts) to be machined. The cutting plane has to be perpendicular to the revolution axis (if the part is revolving), and there is no possibility here of performing cuts perpendicular to any point of a profile, as in operations for plane mouldings. The finishing phase may also be different in revolution operations, as the saw blade may perform a contour movement following the profile in the direction of the revolution axis in order to remove a thin layer of remaining material.

Same machine may also make indexed parts which, in appearance, are very similar to revolution parts, except the process is not a turning process (because the part cannot be rotating when the blade is cutting), although the full perimeter is machined through step-by-step rotating movements of the part.

Basically, saw blade machines may be classified in two types: lathe machines and contour cutting machine. In two-axis lathe machine the part is fixed in a chuck attached to the spindle. Cutting tool (the saw blade) in mounted on a moving bridge with two linear axes movements.

Contour cutting machines simplest configuration would have 3 axis movements (where for a fixed X position, cuts may be performed by moving the disc in the Y direction, while the disc also may go into the stone through the Z axe). A more complex configuration adds two additional axes to the saw blade tool support. Therefore, it would be possible to perform oblique cuts (not just cuts in the Y direction, but following X-Y linear paths), as well as cuts in planes different from the vertical. However, these two additional axes may move just from 0º to 90º.

Moreover, there could be additional axis in the machine table, although they are usually constrain to a specific range (for example, from 0º to 90º and from 0º to 45º respectively), and sometimes, in indexed tables, only a set of fixed angles are allowed.

In the proposed systems, for each custom machine there is a CAD solid model reproducing one of these kinematics models (or a similar one), and with the corresponding axis and with the corresponding limits and relations between them.

### 3.2 Machine Control System (Control System Model)

The machining system architecture (Fig. 4) is built around two independent processes communicated through messages: high and low level process. The low level process is the axis motion controller, alarm management and input/output management. It is running in a Beckhoff embedded PC system and programmed with IEC 1131. The high level process handles the man machine interface (MMI), implements the movement planning and the movement orders dispatcher, and manages the machining and running parameters specification. It runs in the same embedded PC but under Windows CE, and it is programmed with “.NET Compact Framework”. The communication between low and high processes is made through ADS (Automation Device Specification). The high level process is composed of a CAD/CAM-embedded system for selecting feature and machine parameters (Man Machine Interface), although profiles for features may be imported from CAD files in DXF format. Shop-floor information (for example, current saw blade diameter) is communicated through the MMI. The resulting file is the input for the machine low-level control module, responsible for axis motion control.

Although it looks like a classic two level architecture, much of the intelligent is in the low level. This means the high level (Windows CE, planning process) does not communicate the low level the trajectories to make a feature, but just their geometric data. Because of the process changing conditions, to get an optimized process, the control or/and the operator should have the ability of making deep changes in the middle of the process (Tonshoff, Hillmann-Apmann and Asche, 2002). ISO 6983 standard limits (ISO 6983, 1982) the implementation of the on-line machining process adaptation (Suh, Lee, Chung and Cheon, 2003), as this implies a full pre-calculation of the tool paths (Erdos and Xirouchakis, 2003). Instead, a common approach for stone cutting machines is embedded CAM systems that directly and continuously generate tool-path axis control movements from
feature definition while taking into account on-line parameters and on-line operator orders. Therefore, the tool path calculation relies on the low level. The low level, depending on the feature parameters to be made (geometry), decides the sequence of cuts to perform (the tool path). These control systems are not “standard” and made for each machine or type of machine.

The control system is performed in the basis of feature machining. For each feature there is a software module to perform. May there be a basic technology feature to be reused to do complex ones, and then, a basic controller function or software module to perform it. So, although more complex features were not defined as made of basic features, the software module to perform the complex one will probably use the basic algorithm (control module) to perform the basic feature. This is the case of the slot feature in stone cutting technology, which is performed by a basic cutting operation and automated with a “single cut control module”. Control Algorithms (modules) to machine complex moulding and turning features are sequences calls to the basic cut algorithm, although in their definition there is cut features explicit.

Customized control software for new machines or to perform new features, implements new modules in two levels. A high level “planning level” which is really new, and a low level for the basic movements which is the same in all machines, or at list it does no change too much.

3.3 Simulation system architecture

The machine simulation system has two objectives. First, simulation supports the control software development and maintenance, because the control software may be executed in a simulated PLC to move a simulated machine. This architecture may be used in the development phase, when the machine has not been yet produced, or to evaluate the response of the machine to user demands (for instance, the response of the machine to a user defined profile to be machined). And second, it also supports monitoring activities of on-line signals from a remote machine and animates the movements of that machine.

The simulation is based on a machine kinematic model (Section 3.1), which is translated to a CAD model (SolidWorks) where main machine mechanic elements have been defined and relations between them have been established according with the model. Then, through a linker process (Fig. 5), relations between the control system (control hardware configuration) and the CAD model variables are set up to visualize the effect of orders calculated by control in the CAD. There are three types of relations, which are specific for each machine model:

Machine-machine relations (Fig. 5, Type 1): These relations are for links between PLC variables. Master variables are linked to slave ones to modify their values. For instance, from an axis position variable (master), a limit switch variable (slave variable) would change its value (true or false).

Machine MMI-panel relations (Fig. 5, Type 2): these relations are to simulate the MMI control panel (buttons, keys, lights, etc), by relating PLC variables with “controls” in the simulated panel.

Machine CAD model relations (Fig. 5, Type 3): These relations are established between PLC variables with information about axes movements (for instance, actual position of each axis), with the CAD position value for the corresponding axis. Therefore, the CAD position follows the actual axis position coming from the PLC, which produces the simulated axis movement.
“reference position variable” coming from the “user program”, the “hardware variable” coming from the encoder, and a full range of dynamic parameters to specify the axis dynamic (max speed, acceleration/deceleration ramps, etc). Moreover, this development environment has the option of simulating the axis movements (that is, simulate new encoder positions as response of a particular “user reference”) having into account the axis parameterization.

Therefore, the difference between a “remote monitoring execution” or a “simulation execution” is just the origin of the encoder signals (whether real or simulated).

3.4 Remote Monitoring/Analysis architecture

Finally, as Fig. 6 illustrates, same systems may be used for a remote monitoring providing there is a remote access to machine signals. If the machine site has an Internet access, the development/maintenance site may specify the remote machine IP and see the control signals as they were in a local network. Unfortunately, it is quit often the stone processing shop-floor are in remote systems (near quarries), with out Internet access. For these cases, shop-floor is provided with a remote GSM (3G UMTS) access point. Following a similar procedure, a connection with the machine is possible and signals may be received (although with some delay).

![Fig. 6. Simulation architecture.](image)

4. CASE STUDY

This real example shows how simulation and remote monitoring would help in remotely interprets the cause of a poor manufacturing process result. The problem appeared when doing a turning part as the Fig. 7 one. The part was incorrect (a part profile was round instead of square), as part of the stone had been removed (as Fig. 7 shows). But this could had been several causes: whether because the machine had inappropriately interpreted the CAD design describing the column profile; or the control algorithm to calculate tool paths from the profile was incorrect; or there were dynamic problems when performing the part, or whether it had more to do with the disc tool behaviour.

To analyse the problem, the CAD file was sent from the shop floor to the machine manufacturer through Internet, and from it, a solid CAD model (SolidWorks) of the part was placed (in the same position as in the shop floor), in the solid CAD model of the machine (the custom-made CAD model of the real machine). Also, shop-floor information as saw blade parameters (diameter, width) was also provided to the simulation/monitoring system.

The first action to analyse the problem was to perform the simulation. Once CAD models were linked with the real machine control software (but local), the CAD program describing the column profile was introduced into the “local” embedded CAM system, to calculate the corresponding tool paths, which may be visualized and analyzed in the simulation system together with the dynamics (speeds) generated data. As all data generated by the simulation seemed to be correct, next step was monitor a real execution. Through a TCP/IP connection, the same machine CAD model was then linked with the real control system machine. A machine process was executed and remotely monitored. First rough cutting phase was correctly executed, without removing stone far from the allowance surface. When the cutting process reached finishing phase, where the disc is moved following the desired profile in the direction of the column axis (Fig. 7 top), the problem appeared again in the part (Fig. 7 centre). However, the remote monitoring did not reproduce the error and the result were the same as with the local simulation, with out any tool path deviation that could produce the defect.

The conclusion was that the problem had been caused because the disc probably bended (Fig. 7 down), whether for an incorrect disc with (too thin), or because the speed was too fast, or because the cuts were too deep. The solution was change the disc for a bigger one, and the problem did not appear again.

![Fig. 7. Turning process.](image)
5. CONCLUSIONS

For special and custom made machines, which are new developments with software made on purpose, time to market is important and it is not possible to perform an as exhaustive programming phase as for “standard machines”. Therefore, problems may arise once the machine is already working on the shop-floor. In stone cutting machines, there is also an issue in the different working conditions the same machine may have to face, as the stock row material (the stone) mechanical characteristics change a lot from one stone kind to other. Also, the tool selection (diamond saw blade) affects the process performance. It is quite often that machine operators ask for support to the machine manufacturer when the machine process is not as good as expected, whether or not it is a machine defect. To support these problems without an excessive cost is an important business factor for machine manufacturers, and any kind of remote support is the most profitable strategy. The paper has shown a remote support systems for monitoring and simulation from which accurate concussions about a remote machine may be extracted.

The system allows working with real control machine system, while the simulation is almost full dependent of the software/hardware real machine configuration. The system has proved its effectiveness in real situations.

REFERENCES