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REAL TIME MONITORING AND AUTOMATIC REGULATION SYSTEM FOR METALWORKING FLUIDS

Kristína GERULOVÁ[1], Martin NEŠTICKÝ[2],
Eva BURANSKÁ[3], Roman RUŽAROVSKÝ[3]

SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA,
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA,
[1]INSTITUTE OF INTEGRATED SAFETY,
[2]INSTITUTE OF APPLIED INFORMATICS, AUTOMATION AND MECHATRONICS
[3]INSTITUTE OF PRODUCTION TECHNOLOGIES,
ULICA JÁNA BOTTU 2781/25, 917 24 TRNAVA, SLOVAK REPUBLIC
e-mail: kristina.gerulova@stuba.sk, martin.nesticky@stuba.sk
eva.buranska@stuba.sk, roman.ruzarovsky@stuba.sk

Abstract

A real-time monitoring and regulation system for metalworking fluids is being constructed to be installed in the Centre of excellence of 5-axis machining at the Faculty of Materials Science and Technology in Trnava. The article is focused on the description of the main components of the monitoring system and preliminary characterization of the software utilized in the regulation. The monitoring system will contain four probes to record real time values of pH, conductivity, temperature and concentration. After processing of recorded data by the LabVIEW software, an adjustment of the Metalworking fluid in the reservoir tank will be realized by the regulation part of the proposed system to optimum properties of the fluid, by adding water or concentrate. The designed device will provide an easy system which will control the quality of used metalworking fluid during its lifetime and maintain it on its optimum condition without human operator's assistance.

Key words

metalworking fluids, monitoring, regulation, LabVIEW, machining

INTRODUCTION

Cutting fluids or metalworking fluids (MWFs) are extensively used to cool and lubricate, flush away chips, and inhibit corrosion during machining operations such as drilling, turning, milling and grinding. MWFs lead to increased tool life, improved work quality, enhanced machine tool life, effective chip management, and reduced process variability (1). Today, a wide variety of cutting fluids are commercially available. Depending on the machining operations carried out and the final surface desired, properties of the cutting fluid required may be oriented either on cooling, lubricating, or both. The effectiveness of cutting fluid depends on a number of factors, such as types of machining operation, cutting parameters and methods of cutting fluid application (2). MWFs, specifically the water-soluble types, are all formulated to operate within a certain range of conditions in areas such as concentration, pH, dirt levels, tramp oil, bacteria, and mold. When fluid conditions exceed this range in one or more of these areas, performance problems can develop. It is, therefore, necessary to have a set of tests, to be run on some regular basis on the fluid mix to keep it within these operating conditions (3). It is very important to design the monitoring and control system so that to maintain the function and hinder the degradation of fluid. The control includes measurement of several parameters, analysis of the information and decisions about countermeasures (mainly addition of biocides, adjustment of the concentration or filtration/cleaning of the fluid) (4). The MWF manager should decide which factors need to be recorded and tracked. These factors should be prioritized and customized for specific facility situations. For instance, in a facility using water-miscible MWFs with good microbiological control in a soft-water area, we can monitore the concentration of the fluid, pH, biological contamination, biocide levels, tramp oil, foaming tendency, corrosion tendency, appearance, odor etc. (5). Historically, microbial contamination of MWFs has been a problem in the metalworking industries, primarily because of potential adverse health effects and microbial growth effects on fluid quality and performance. Fluid degradation from microorganisms may result in changes in fluid viscosity, and the acid products of fermentation may lower the pH of the fluids, causing corrosion and leaks in the metal working fluid system (6). In water-based fluids microorganisms introduced from the machines surroundings are an additional problem, since their metabolism decomposes organic components of the fluid to acidic products, which increases the corrosion probability of the machine. In order to maintain the optimum performance of the cutting fluid, its properties have to be kept within certain limits. This is achieved through the addition of water and chemicals to balance their composition during operation. All cutting fluids are designed to operate in the alkaline range at a pH between 8.0 and 9.5, because alkalinity helps to control corrosion and minimize growth of microorganisms. As mentioned before, the decreasing pH in cutting fluids is usually the result of bacterial activity and can serve as an indicator for the overall state of the fluid (7). pH determines how acidic or alkaline the metal removal fluid is, and it is important to record it daily. A decrease in pH may result in increased corrosion, foul odors and destabilization of the metal removal fluid. Concentration is the most important variable to control. Conductivity can give some information on the quality of a metal removal fluid. The conductivity of fluid will depend on the build-up of water hardness through evaporation, dissolved metals, and other contaminants. Conductivity data should be compared to concentration values to aid in determining contamination (8). Conductivity can be altered by the mix concentration, build-up of water hardness, build-up of chloride or sulphate from the water, mix temperature, dissolved metals, and just about any other contaminant. Since so many ever-changing variables can affect conductivity, a single reading is of little value. Observing any trends in these conductivity readings over a period of time may be useful in assessing the mix condition and aging, as well as helping in problem solving for residues or unstable mixes (3). Maintenance of machines, coolant lines and pumps is an integral part of fluid management. Clean machines use MWFs more economically and extend fluid life. Any dirt and oil allowed to remain in the system simply recirculates, resulting in plugged coolant lines, unsightly machine buildup and bacterial growth (9). Before loading the system with the fresh fluid, it is necessary to clean the whole system (3) in order to keep biological growth in check and maintain proper system operation. Simple flushing of cleaning solution through the system does not provide adequate cleaning. To clean a machine system properly, biocide should be added to the dirty fluid and allowed to circulate before pumping out the reservoir. All chips, swarf and visible deposits should be removed (10). The microbial contamination of water miscible metalworking fluids (MWFs) is a serious problem in metal industry. A good maintenance of MWF re-circulation systems can extend the lifetime of coolants and ensure the quality of the machined parts (9).

Concept of MWFs monitoring and regulation system

In Figure 1, there is the block schema of the whole monitoring and regulation system. As it can be recognized from the block schema, the monitoring and regulation system contain four tanks, of which one is utilized for the measurements, one is utilized as a mixed tank, one is the machine tank reservoir and the last one contains concentrate of the selected fluid.

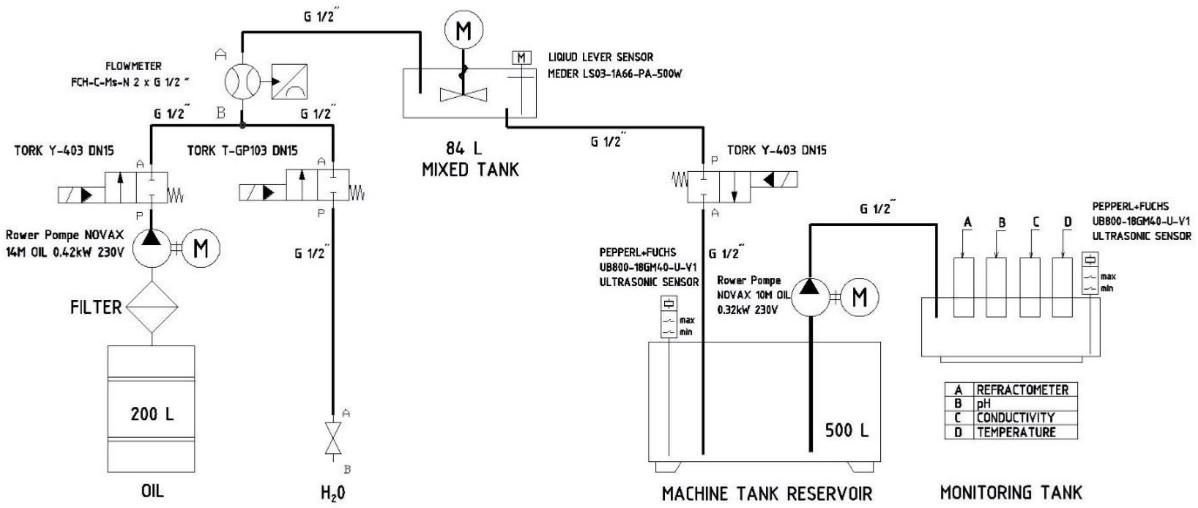

Fig. 1 *Block schema of the whole monitoring and regulation system for the MWFs*

Machine and utilized MWFs

For modelling the monitoring and regulation system, we selected the machine of DMU 85 monoBLOCK (Figure 2) which operates at the Faculty of Materials Science and Technology, the Centre of Excellence of 5-Axis Machining. This milling machine is for 5-axis simultaneous machining, high-dynamics high-speed machining, high-torque high-performance machining, or ambitious volume parts production requiring three to five axes. Machined materials are different, mainly aluminium alloys and steels. Utilized metalworking fluid is Syntilo 9913. It is a pH-neutral synthetic coolant which has been developed for heavy duty machining of aluminium. It is recommended for grinding, honing, milling, turning, drilling and tapping of aluminium and other aerospace alloys. It is boron, chlorine, phenol and nitrite free.

Fig. 2 *Universal milling machine of DMU 85monoBLOCK*

Machine tank reservoir

Parameters such as the maximum surface level, total volume and dimensions of the tank will be needed to enter into the regulation software as input data. The currently considered tank side belongs to the machine of DMG DMU 85 (Fig. 3). In the selected tank, an ultrasound sensor for measurement of actual surface level of the fluid was installed. The active volume of the tank is 500 liters.

Fig. 3 *Tank reservoir of DMU 85monoBLOCK*

Monitoring tank

In the monitoring tank, we plan to install three different probes for the measurement of the pH value, conductivity and temperature. The monitoring tank is filled with the metalworking fluid from the tank reservoir by the pump which supplies the fluid into the monitoring tank under constant flow. The concentration probe is installed in the pipe right behind the pump. The fluid returns to the tank reservoir by the passive utilization of overflow installed at the defined level. A safety switch controlling possible breakdowns of the overflow is installed above the overflow to stop the pump when an accident such as overflow jam happens. The suction pipe is equipped with the suction strainer to separate fine metal parts from machining or other impurities, and to protect measuring probes against its damage. The total volume of the monitoring tank is constructed to hold 3 liters of active fluid and the tank is constructed as an open system. All probes will be connected to the real time measurement unit while data will be sent to the LabVIEW software.

Mixed tank

In the mixed tank, the self-preparation of the final fluid to be added to the tank side as a mixture of water and specific concentrate is carried out. The total value of the active fluid is designed to be 84 liters (active volume of 72 liters). The concentrate will be added by the pump directly to the mixed tank. Behind the pump, there will be a valve and a flow meter. Flow meter will indicate when the valve closes and the pump will stop adding the concentrate. Water is added directly from the water supply system only by installing the valve before the flow meter. The water is added into the mixed tank primarily, so the added concentrate has better conditions for proper mixing. The mixed tank contains a stirrer which will switch on when the tank starts to be filled with water. When the fluid is prepared, a valve at the bottom is opened and the whole fluid drains by gravity to the tank side. The mixed tank was fitted with two level sensors which coordinate the mixed tank filling and draining. One more overflow installed above the upper level sensor is also being considered.

System components characterization

pH sensor – As a pH sensor, the pH-BTA sensor of Vernier which is gel-filled, sealed with epoxy body, Ag/AgCl. Response time is 90 % of final reading in 1 second, was selected. Accuracy is +/- 0.2 pH units. Utilizable temperature range is 5 – 80 °C, pH range 0 – 14 (11).
Temperature sensor – For the measurement of the temperature, we selected the TMP-BTA stainless steel temperature probe of Vernier. It is utilizable for the temperature range -40 to 135 °C, with the maximum temperature that the sensor can tolerate without the damage 150 °C. Resolution in the expected range of MWFs temperature is 0.03 °C (0 – 40 °C) and 0.1 °C (40 – 100 °C). The temperature sensor probe is 20 kΩ NTC Thermistor. Response time is 10 seconds in mixing medium (12).
Conductivity probe – For the conductivity probe, we selected the CON-BTA probe also of Vernier with the ABS body and parallel carbon (graphite) electrodes. The Conductivity Probe has three ranges, providing the optimal precision in any given range. Low Range is set from 0 to 200 $\mu S.cm^{-1}$ (0 to 100 $mg.l^{-1}$ TDS), it has the resolution 0.1 $\mu S.cm^{-1}$ (0.05 $mg.l^{-1}$ TDS) and accuracy ± 8 % of the full-scale. Mid-Range is set from 0 to 2000 $\mu S.cm^{-1}$ (0 to 1000 $mg.l^{-1}$ TDS), it has the resolution 1 $\mu S.cm^{-1}$ (0.5 $mg.l^{-1}$ TDS) and accuracy ± 3 % of the full-scale. High Range is set from 0 to 20 000 $\mu S.cm^{-1}$ (0 to 10 000 $mg.l^{-1}$ TDS), it has the resolution 10 $\mu S.cm^{-1}$ (5 $mg.l^{-1}$ TDS) and accuracy ± 4 % of the full-scale. Accuracy using custom calibration is ± 2 % of full-scale reading for each range. Response Time is 98 % of full-scale reading in 5 seconds, 100 % of full-scale in 15 seconds. Temperature Compensation is automatic from 5 to 35 °C, and the utilizable Temperature Range without damage is 0 to 80 °C. Cell Constant is 1.0 cm^{-1} (13).
Refractometer probe – As a refractometer which is used for the concentration measurement, we selected the PR-111 in-line process refractometer of AFAB enterprises. The probe for measuring consists of a stainless steel sensing head with a sapphire prism. Measurement is carried out after calibration to 4 – 20 mA output. Measuring range provides 0 – 100 Brix equivalent to 1.3330 – 1.5435 of refractive Index. Accuracy is ± 5 % of Span. Temperature range is from -34°C to 121°C (14).
Oil pump installed for MWF concentrate pumping – For pumping the concentrate of MWFs from the canister, we selected the Rover Pumpe NOVAX 14M Oil. It is a classic self-priming lateral liquid ring pump with starry impeller. This particular type of hydraulics provides the

pump with an extraordinary self-priming capacity, also in absence of a continuous flowing of the liquids in suction (presence of air or other gases). Ambient temperature range is set from 4 to 40 °C, while the maximum temperature of pumped liquid is 35 °C. Maximum working pressure generated by the pump is 1.5 – 2 bar. Maximum flow for oil is 10 $l.min^{-1}$ (15).

Oil pump installed for MWF pumping from the tank reservoir of the machine – The selected pump is very similar to the previous one. This pump - the Rover Pumpe NOVAX 10M Oil has lower flow set to 5 $l.min^{-1}$ (15).

Valves for MWF concentrate, and for the water – the valve is the same as will be utilized for the mixed tank. We selected the electromagnetic valve TORK Y-403 DN15 which is the fuel oil solenoid valve. This valve is utilizable for oil liquids. It works under the pressure from 0.5 to 12 bar and under the temperatures from -10 to 160 °C. The tube and all internal parts are made of stainless steel. Position – normally closed. For the water, we selected the electromagnetic valve of TORK T-GP103, DN15 with position – normally closed. It works under the pressure from 0.35 to 12 bar and under the temperatures from -10 to 80 °C. The tube and all internal parts are made of stainless steel (16).

US surface level sensor – for the measurement of actual surface level in the machine tank reservoir, we selected the ultrasonic sensor UB800-18GM40-U-V1 of Pepperl+Fuchs. Sensing range is set to 50 – 80 mm.

Principle of the fluid concentrations regulation

The system of process control and monitoring was designed in LabVIEW. A simple flowchart is depicted in Figure 4. The PCI-1711U/UL, a universal PCI bus multifunction card, provides data acquisition of a physical phenomenon. The card offers the digital input/output measurement and performs a multiple-channel 12-bit A/D conversion which ensures a sufficient functionality for the proposed system. LabVIEW monitors five physical characteristics of the fluid. The values of pH, conductivity and temperature are archived in an external file in a specified time intervals. Values of concentration and level of liquid in the machine tank reservoir are archived also, but these two parameters are the main according to which LabVIEW performs an action when a specific combination of both is out of established acceptable boundary. Before LabVIEW launches the monitoring and controlling of the system, it is necessary to enter the information to the program about desired concentration of the fluid and dimensions of the Mixed and Machined tank. Volume of the Mixed tank (V_{MIX}) and Machined tank (V_{MAX}) is calculated. Fluid level in the Machine tank is monitored. Fluid level determines the actual volume of fluid in the Machine tank (V_{ACT}). Based on the set information, LabVIEW determines the value of a fluid level in the Machine tank which corresponds to the loss of fluid volume equal to the total volume of the Mixed tank. When the level falls under this value, LabVIEW starts the procedure for refilling the tank. The fluid in the Mixed tank is prepared in such concentration (C_{MIX}) so that draining of this liquid to the Machine tank eliminates deviation from the actual concentration (C_{ACT}) of fluid in this tank with respect to the set point of concentration (C_{SET})

$$C_{MIX} = \frac{(C_{SET}\,V_{MAX} - C_{ACT}\,V_{ACT})}{V_{MIX}}\,. \qquad [1]$$

LabVIEW calculates the limits for concentrations of fluid in the Machine tank (Eq. 2). Beyond these limits, it is impossible to adjust the actual concentration by adding fluid from the Mixed tank.

$$\frac{C_{SET}\cdot V_{MAX} - 100\%\cdot V_{MIX}}{V_{MAX} - V_{MIX}} < C_{ACT} < \frac{C_{SET} V_{MAX}}{V_{MAX} - V_{MIX}}. \qquad [2]$$

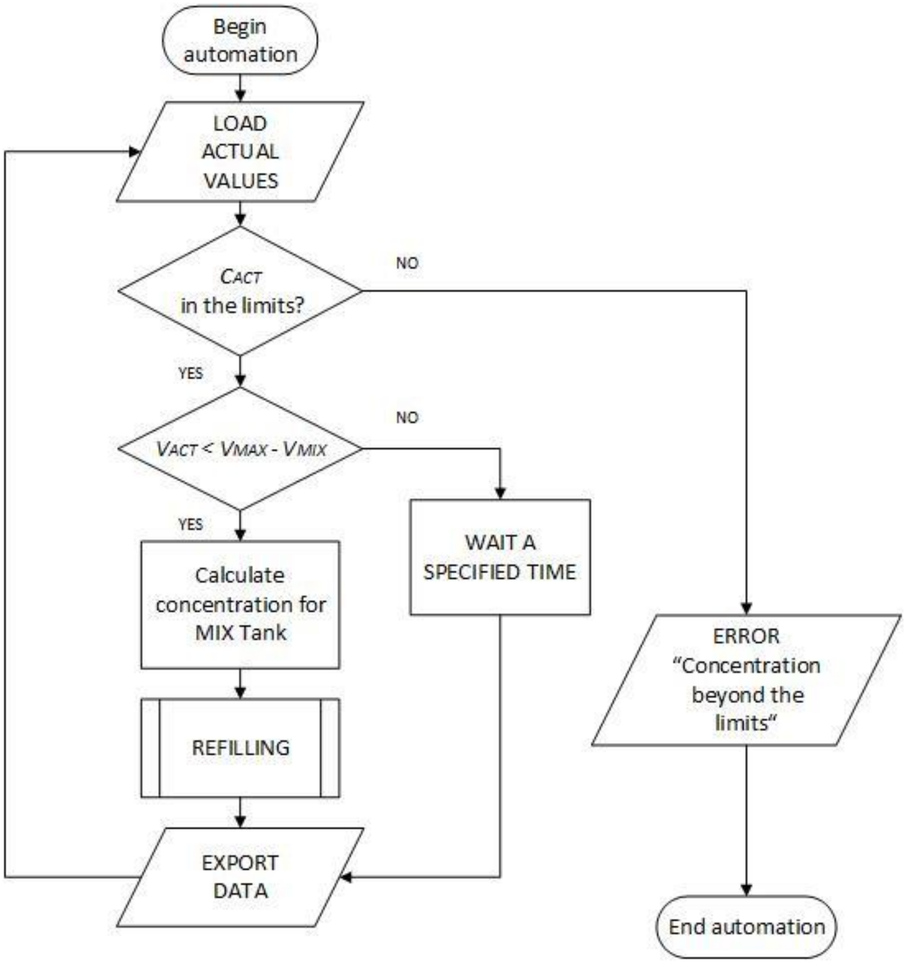

Fig. 4 *Flowchart of the LabVIEW*

In such case, LabVIEW shows an error message and ends the program. This scenario is unlikely and probably indicates either a failure of the system or the fact that the fluid in the tank was contaminated with unknown liquid.

CONCLUSION

A real-time monitoring and regulation system for the metalworking fluids is being constructed to be installed in the Centre of Excellence of 5-axis Machining at the Faculty of Materials Science and Technology in Trnava. The main components of the monitoring and automatic regulation system were defined. Also, the program to be utilized in the regulation was preliminary characterized. The whole system will be installed at the machine run as a pilot plant. After successful testing, it will be approved for its versatility at another machine. The designed device will provide a simple system which will control the quality of used metalworking fluid during its lifetime and maintain it on its optimum condition without human operator's assistance. The whole system is designed as universal for both synthetic and semisynthetic fluids; while all parts are carefully chosen from the market aspect, to meet the economic viability.

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