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DESIGN OF MECHATRONIC SYSTEMS WITH HIGH AVAILABILITY IN VERY HARSH OPERATING CONDITIONS

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ABSTRACT

The use of mechatronic systems in very harsh environments requires a strengthened and seamless interlocking of the individual components. This paper presents the methods and approaches that were developed during a research project for the stabilization and increase in the reliability of such systems. This includes a catalog of measures for the mechanical and electronic design of such intensely-used systems as well as a software framework. Using the example of an inline marking system for castings, it is shown how mechatronic systems installed in harsh operating environments can be protected constructively as well as through the use of modern control, regulation, and monitoring systems. The developed catalog of measures is based in the first step on a questionnaire, in order to investigate the primary features of the system. Based on this questionnaire, in the second step the mechanical and electrotechnical loads were determined. Harsh operating environments can be understood as high loads with metallic and non-metallic dust, very high temperatures (>500°C), high electromagnetic interference, and high mechanical loads. In the third step, corresponding countermeasures can then be selected from the catalog of measures and combined as appropriate. Similar to these measures, in a fourth step – after the initial mechanical and electrotechnical design has been completed – the necessary software components for the controlling, monitoring, and protection of the system can be selected.

In the final step of the design, the overall system is examined and – through any necessary iteration of steps two to four – the interfaces between and the requirements of the individual mechatronic components are adjusted.

Index Terms **–** mechatronic systems, harsh operating conditions, monitoring, protection, development framework

1. INTRODUCTION

The use of modern mechatronic systems and the associated control systems is making inroads into an ever-increasing number of fields that up to now were, in terms of control systems, only covered by specific applications such as safety-related controls. The increasing use of standard components from the consumer sector, such as embedded systems based on x86 architecture like the Intel Atom processor, results in more efficient applications. However, the design process and the system design must be adapted to the harsh operating conditions [7]. A simple adaption of the previously applicable measures and implementation approaches from the field of safety-related control systems is not possible. These systems are specially constructed for the respective fields of application and offer longstanding, proven safety measures. The costs of such systems are however much higher and the processing speeds lower. There is therefore demand for currently available systems to be adapted for the controlling of mechatronic systems in very harsh operating conditions as well.

One approach here is the presented questionnaire with its associated catalog of measures. This takes the form of a modular system or framework that supports and simplifies the design of control components. The currently developed system does not meet the demand for a completed product, since many requirements and necessary measures can only be developed through interaction with the user and accepted into the system after a successful field trial.

In this article a project from the technical casting field has been selected as an example. It considers a marking system for castings that, in contrast to the current system, embeds the marking directly during the casting process as a Data Matrix code in the part. The marking system therefore sits directly in the mold and is exposed to high temperatures, dust, and mechanical strain.

2. OPERATING ENVIRONMENTS

In harsh operating conditions, depending on the application and implemented mechatronic system, there are different influences that need to be understood. These can be high temperatures, aggressive process media in liquid or gas form, metallic and non-metallic dust particles, electromagnetic influences, or mechanical forces like vibrations or jarring. Depending on the nature of the mechatronic system, it can be sensitive to some or all of these factors. Looked at simply from a technical standpoint, there are protective measures for all of these factors, but which, in the worst-case scenario, mutually exclude one another or at least influence each other in their use. In high dust-exposure situations for example, direct cooling of the components by a ventilation system is impossible, so other processes, such as a compressed-air cooling system or a heat exchanger, must be used instead. Depending on the type and extent of the individual forces and the resulting total exposure of the system, there are specific requirements on the mechanical and electrotechnical design as well as on the construction and implementation of the controlling algorithms of the mechatronic system to be developed.

3. SYSTEM REQUIREMENTS

To obtain an overview of the system requirements, extensive requirements engineering is necessary. This is conducted and documented in most development departments in the appropriate manner [3]. Along with this gathering of the requirements, which on the whole relies upon the support of the user, a very precise analysis of the above-mentioned influences and stresses of the operating conditions on the individual components also needs to be undertaken. The emphasis of this analysis must be appropriately weighted depending on the characteristics of the different branches of mechatronics [4].

3.1. Constructively Facets

This section encompasses the mechanical construction of the system. The analysis must therefore consider the physical and chemical influences (dust particles, process media, vibrations, temperature). Depending on the degree of mechanical sensitivity of the system, the appropriate thresholds must be defined here according to the requirements analysis. A simple construction, for example according to the specifications of International Protection (IP) and the associated types of protection, represents only passive protection for the system and does not take advantage – or at least not sufficiently so – of the possibilities offered by intelligent protection mechanisms with appropriate sensors and controlling algorithms [2]. With regard to the described marking system, this scenario means that the particles and temperature will have a very substantial impact on the availability of the system. The very strong mechanical construction and the resulting resistance against vibrations and jarring is sufficient as far as the operating environment is concerned. Corrosion and contamination on the outside of the housing are also not critical. What is important is the prevailing temperature while the mold is heating up and also during the actual casting process, during which temperatures of up to 800°C will be reached for several minutes. Since the marking system's electromagnetic actuators are constructed to only withstand temperatures of up to 170°C, several independent active and passive cooling systems are required so that they can withstand the outside temperatures. Along with the high temperatures, the exposure to particles also reduces the lifespan of the system. This problem must be counteracted in various ways, such as sensor-controlled pulsed compressed-air flushing, the implementation of automatic cleaning cycles and cleaning models, and motion monitoring of the system.

3.2. Electrotechnical Loads

The main aspect in the field of electronic construction of a mechatronic system is based on the electromagnetic compatibility (EMC) of the proposed system. Here there are a variety of regulations, standards, and reference sheets, with this field of work being the topic of many research projects. In the practical application this means that the developer must adapt the requirements analysis to these guidelines. The difficulty during the design and implementation lies in knowing the current regulations and the appropriate countermeasures. For the final tests, testing devices and EMC labs are available [8]. For the chosen example, the application in the technical casting field means a coupling of very powerful interference signals on the supply, sensor, and communication lines. These signals must be offset to the greatest extent possible through appropriate circuits as well as passive protective measures like filters and shielding.

3.3. Software Development

As explained in [5], the design and implementation of software systems for embedded systems are subject to stricter standards on engineering than for office software. This is because embedded software requires greater reliability as a result of the higher level of availability required as well as possible safety-related uses.

In [6], a UML-based model for the design of an embedded system is proposed that, because of its modularity, is advantageous for the component-based system visualized here. By using this modular approach, specific modules with corresponding measures can be provided for the individual requirements.

3.4. Control of Mechatronic Systems

In summary, it can be said that the additional factors not only influence the individual components of the mechatronic systems under the described operating conditions, but may also affect the whole system (Figure 1), comprehensive requirements analysis should be undertaken as outlined in [9], in which the individual components, their connections, and the respective factors should be taken into account. The presented questionnaire and catalog of measures was developed for this purpose.

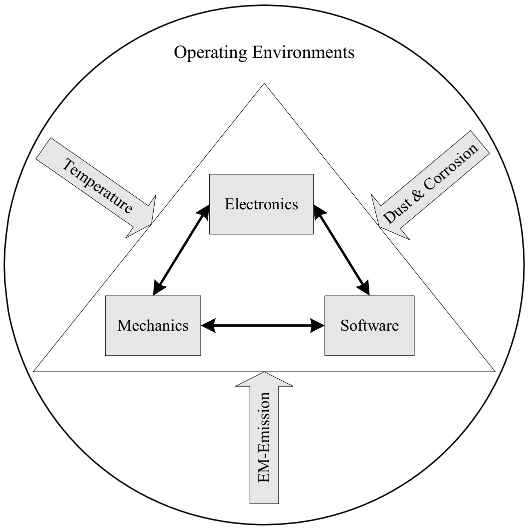

Figure 1: Structure and outside influences

4. QUESTIONNAIRES

The questionnaire for the requirements engineering is currently in paper form with one set of questions for the respective individual components described above. In this way, the developer can qualitatively and quantitatively record the identified requirements. This approach also supports the requirements engineering, as the questions seek to create interconnections between the individual components of the mechatronic system and the system environment. The results of the questionnaire are then matched with the available technologies and the modules on hand in the catalog of measures. With the help of this comparison, the best possible coverage of the ascertained requirements is strived for through the features of the selected modules and technologies. The issue of energy use has not yet been considered and the field of real-time capability only qualitatively and not quantitatively analyzed. As a result, only hard and soft real-time requirements are distinguished between.

The essential categories of the questionnaire follow the functional areas of mechatronic systems to be covered and are as follows:

- Operating environments (heat, dust, vibration, etc.)
- Constructive requirements
- Electrotechnical loads
- Software and control

Later on in the project, it is planned to extend the paper questionnaire to a computer-based system. This will allow users to assign appropriate modules from a dynamic list to the requirements determined by the questionnaire. In addition, a support system is to be provided that, based on the requirements analysis, selects already-known configurations from a knowledge base. This approach is based on care-based reasoning (CBR) [1] and will further support the user.

5. CONCLUSION

Modern mechatronic systems and their control systems are making inroads into fields that up to now were reserved for safety-related control systems and applications or which were previously not considered due to the harsh operating conditions and the resulting requirements. The described approach for the analysis and synthesis of control components for mechatronic systems showed that a systematic use of the requirements analysis and the progressive composition of existing modules can significantly reduce the development time. The developed questionnaire coupled with the catalog of measures can support the developer in the selection of appropriate measures and thus not only reduce the development time but also increase the availability of these systems. The current form of the questionnaire is to be extended to an electronic (automatic) version, which thanks to CBR will be able to derive suggestions for future systems based on existing modeled systems, interactively supporting the developer in his designs. In addition, the questionnaire as well as the catalog of measures will be continually extended.

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