REFURBISHMENT OF THE CRANE IN THE REACTOR HALL AT FRM II: CHALLENGES AND LESSONS LEARNED

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The Research Neutron Source Heinz Maier-Leibnitz (FRM II) at the Technical University of Munich (TUM) has been in operation since 2004, with the crane in the reactor hall serving as a vital component for refueling and various transport operations within and around the reactor pool.
However, after about 20 years of operation, spare parts are increasingly difficult to get, yielding a need for an overall refurbishment. Most importantly, changes to the German nuclear safety standards (KTA) require extensive modifications to the crane's control system. Consequently, the decision was made to completely replace the electrical and control system of the crane.
This paper provides an overview of the procedure for realizing large projects in compliance with German nuclear safety standards, including the challenges encountered during this specific project. The paper also outlines the most significant lessons learned during the refurbishment of the crane and will give an overview of the new control system.

1. Introduction

The Research Neutron Source Heinz Maier-Leibnitz (FRM II) at the Technical University of Munich (TUM) has been in operation since 2004. Many of the systems were installed during the construction phase in the late 1990s. One of the most vital systems is the crane in the reactor hall. The crane is a double girder overhead crane with two separate hoists, as shown in fig. 1 and fig. 2, and was built in 1998. The main hoist has a lifting capacity of 20 t and is used for many heavy-load operations within and into the reactor hall, such as handling of storage containers for high-level nuclear waste. The auxiliary hoist has a lifting capacity of 3.2 t and is used for various transports within and around the reactor pool. It also serves as refueling machine. Since transportation of fresh and spent fuel elements is done using this crane, it has to meet the highest standards according to the German nuclear safety standards [1, 2].

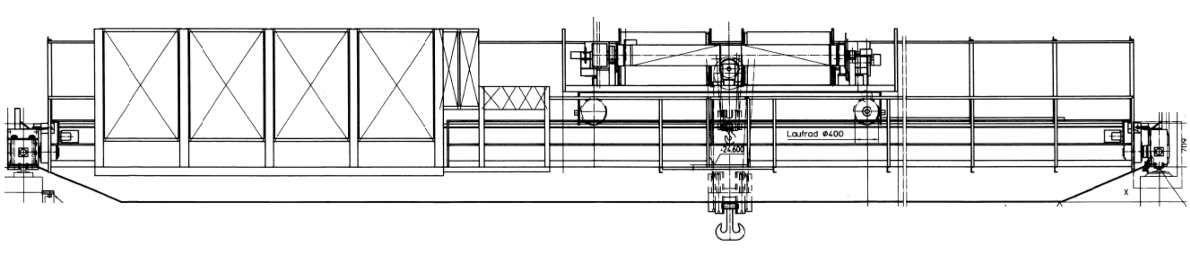

Figure 1: Overview of the Crane - side view

After about 20 years of reactor operation and more than 25 years of crane operation, an increasing number of maintenance works have become necessary, and more and more components are becoming defective. Replacing these components with identical parts is usually not possible since most of the used components have already been discontinued and inventory stocks have been depleted. Therefore, these components need to be replaced with similar or successor components. Since this implies a change to the crane's system, extensive documentation, testing, and verification work is necessary, and everything needs to be approved

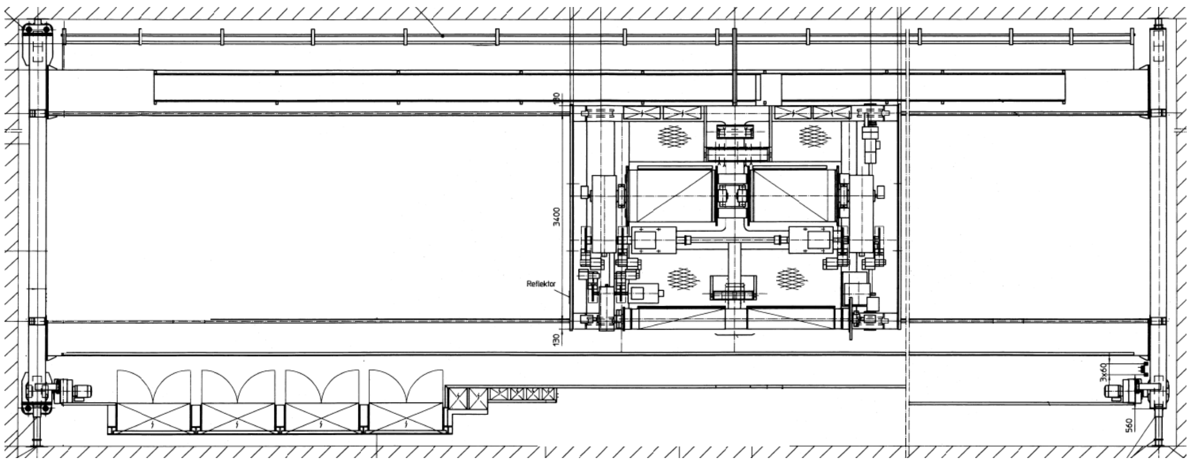

Figure 2: Overview of the Crane - top view

by the governing authorities or an authorized expert. A brief overview of this process in accordance with German regulations is given in section 2.

Furthermore, during the past 20 years, several changes have been made to the German nuclear safety standards. Usually, it is necessary to apply these changes to already existing systems. Since the crane's control system is built using analog, conventional circuit systems, modifications cannot be easily done. PLC controllers or similar control systems were not used. Therefore, applying the necessary changes would imply an extensive change to the existing control system. It was estimated that replacing the whole electrical and control system was more time and cost effective than applying only the necessary changes. This solution is also more future-proof since latest components will be used, and availability of spare parts will be guaranteed for a long time.

2. Overview of Change Procedure

In accordance with German nuclear regulations, most modifications of existing systems and installation of new systems require approval from the nuclear regulator or its authorized expert (TSO). The approval process depends on the nature of the change and the significance of the affected system for safety.

Generally, before any work is done on a system, the changes need to be carefully planned and thoroughly documented. Afterwards the planning documents need to be submitted to the regulator and its TSO for review. The review process may take anywhere from a few weeks to several months, depending on the complexity of the changes. In most cases, additional modifications and clarifications are requested before receiving approval to proceed with the actual modification.

In this specific case, the change was classified to the second highest category for modifications. The technical planning for the refurbishment began in mid-2019 following a Europe-wide tender. The first version of the documents, which primarily consisted of electrotechnical diagrams, functional descriptions, and test and inspection sequence plans, was finished in August 2020 and subsequently transmitted to the TSO. It took two revisions and extensions before receiving approval in March 2022, with some remaining open points that needed to be addressed in the following months.

The purchasing and manufacturing phase began immediately after getting the approval. However, it still took some time before the factory acceptance test and EMC testing could be conducted in January and February 2023. The on-site work commenced immediately afterwards and was completed in April. The subsequent acceptance and functional testing were finished in May 2023. This brief summary of the schedule shows that the entire process took a significant amount of time, more than initially anticipated. Considering that three other similar cranes at FRM II will need to be refurbished in the near future, the lesson learned is to allocate much more time for unforeseen events and inevitable delays.

3. Overview of New Control System

The core components of the new control system are two independent PLCs, an operational control system and a safety-related control system. The operational PLC is responsible for all standard control functions. Since these functions correspond to a conventional crane control system found in many installations, further details are not covered here.

The safety PLC is responsible for monitoring the operational PLC and all other components and parameters. In case of inadmissible operating conditions, inadmissible excess of limitations, malfunction, or failure, it ensures that the entire system transitions to a safe state. To ensure that these monitoring functions receive the correct input signals at all times, the highest requirements are placed on the sensors and the transmission. In general, the various functions must meet Performance Level d or e according to [3]. The specifications are listed in the applicable nuclear safety standards [1]. This means that in addition to failsafe components, high levels of redundancy and diversity must be provided. Detailed calculations of the failure probability had to be performed for all functions and signal paths, which typically include sensors, control, shutdown logic, and actuators.

The redundancy and diversity are explained using the example of position measurement. Since the crane is used for transporting fuel elements, precise and failsafe positioning is required. Distance measurement is performed using redundant and opposite laser sensors, as shown in fig. 3. Additionally, the current position of the crane is determined using encoders on the motor shafts. Deviations between the determined positions by either two lasers or by a laser and the encoder result in an immediate safety shutdown.

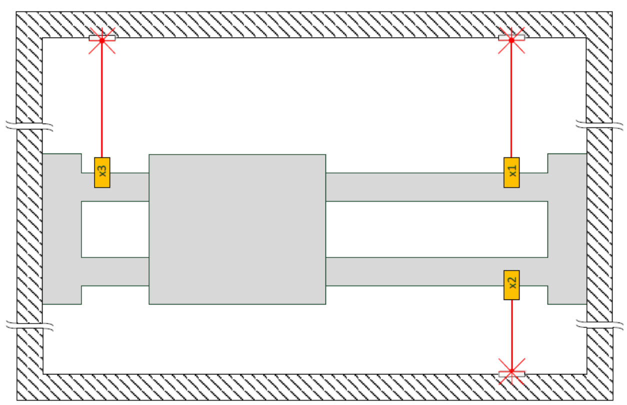

Figure 3: Laser System for Position Detection

Many other safety functions, such as height measurements for lifting mechanisms, load measurements and resulting shutdowns in case of overload, signal transmission for radio remote controls, as well as monitoring of standstill and direction, are built on a similar principle.

4. Hoist Brake System and Encountered Issues

The 20 t hoist is equipped with four hoist brakes, including two service brakes and two auxiliary brakes, as shown in fig. 4. The brake system of the 3.2 t hoist is slightly different. Since it consists of only one motor and one gearbox, there is only one operating brake and one auxiliary brake. In addition, a safety brake is

installed, which is integrated with the hoisting drum and only brakes down the drum in case of gearbox failure.
During regular operation, braking is performed using frequency converters, and the brakes engage only when the crane is almost at a standstill. The brakes must be tested according to the German nuclear standards [1, 2]. In a static brake test, each individual brake is tested to ensure that it can safely hold the rated load of 20 tons without causing the load to drop. Furthermore, a dynamic brake test is conducted.

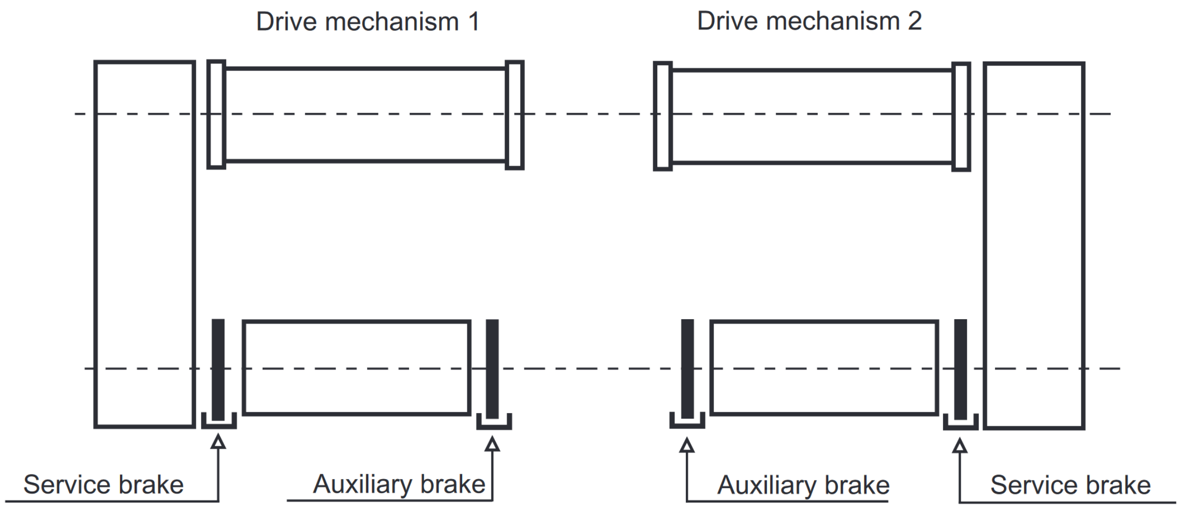

Figure 4: Schematic view of 20 t lifting unit and brakes

According to the applicable standard, the static holding force test of each individual brake is performed first. In this test, the test load of 20 t is lifted, and then all brakes except the one being tested are released. This test was conducted for each brake one after another. Each of the brakes was able to hold the load without any noticeable drop. None of the brakes exhibited any anomalies during this test.
Subsequently, a dynamic brake test was conducted. For this purpose, the test load of 20 t is lowered at maximum speed. Then the test command is issued. The frequency converters, which normally contribute to the braking effect, are abruptly switched off and therefore cannot provide any braking effect. At the same time, various brakes are activated. The sequence in which the brakes are to be activated is specified by the German nuclear standard: first, all brakes together, then every possible combination of two brakes, and finally each brake individually. The reaction time t_r (time from the shutdown command until the brake engages) and the braking time until complete stop t_b are measured. These must correspond to the calculated requirements. The course of such a recorded characteristic curve is shown in fig. 5. At the beginning, the load is moved with a maximum lowering speed of approximately 1500 rpm. At time t=0, the command to switch off the frequency converters and engage the brakes is given. The converter shuts down almost immediately, but the brakes require the time period t_r to engage. Consequently, there is an additional acceleration of the load. Only after the reaction time t_r has elapsed does the braking effect begin, and the load is brought to a complete stop within the time period t_b.
The measured times t_r and t_b were compared with the specifications from the initial installation of the crane. Not all such data were available from the commissioning phase almost 25 years ago. There were only values for individual brakes available, but not the target values for the different combinations. A service brake of the 20 t hoist was found to be not properly functioning and needs to be repaired. Finally, it was found that the braking times were partially too short and partially too long. Too short braking times result in increased mechanical stress on all components of the hoist. Too long braking times lead to a greater coasting distance of the crane, which could damage components located below the load in case of a failure. Calculation of the

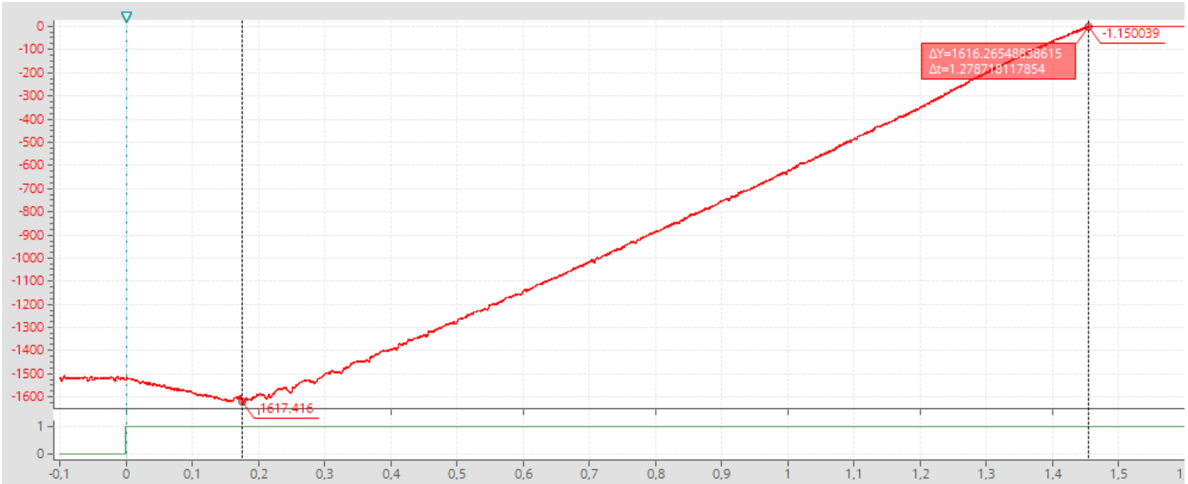

Figure 5: Characteristic Brake Curve

missing target values and reworking of the brake identified as not properly functioning is a requirement to finish the commissioning of the crane. Currently, work is underway on these points, and therefore, no final results can be presented yet.

5. Summary

In this paper, an overview of the recent refurbishment of the crane in the reactor hall of FRM II was provided. An overview of the new control system was given, as well as the basics of the process for making changes to safety-related components in a nuclear facility in Germany. During the renovation, a test of the hoist brakes was conducted. The experiences during commissioning were summarized and presented.
In the near future, a similar renovation will be carried out for three additional crane systems at FRM II. The experiences and insights gained will contribute to an even better and faster outcome in the planning and implementation process.

References

[1] *Design of Lifting Equipment in Nuclear Power Plants*, KTA Std. 3902, 2020-12.

[2] *Inspection, Testing and Operation of Lifting Equipment in Nuclear Power Plants*, KTA Std. 3903, 2020-12.

[3] *Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design*, ISO Std. 13 849-1, 2015-12.