Research Neutron Source
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Evaluation and Optimization of Hoist Brake Performance Following Crane Control System Modernization at FRM II

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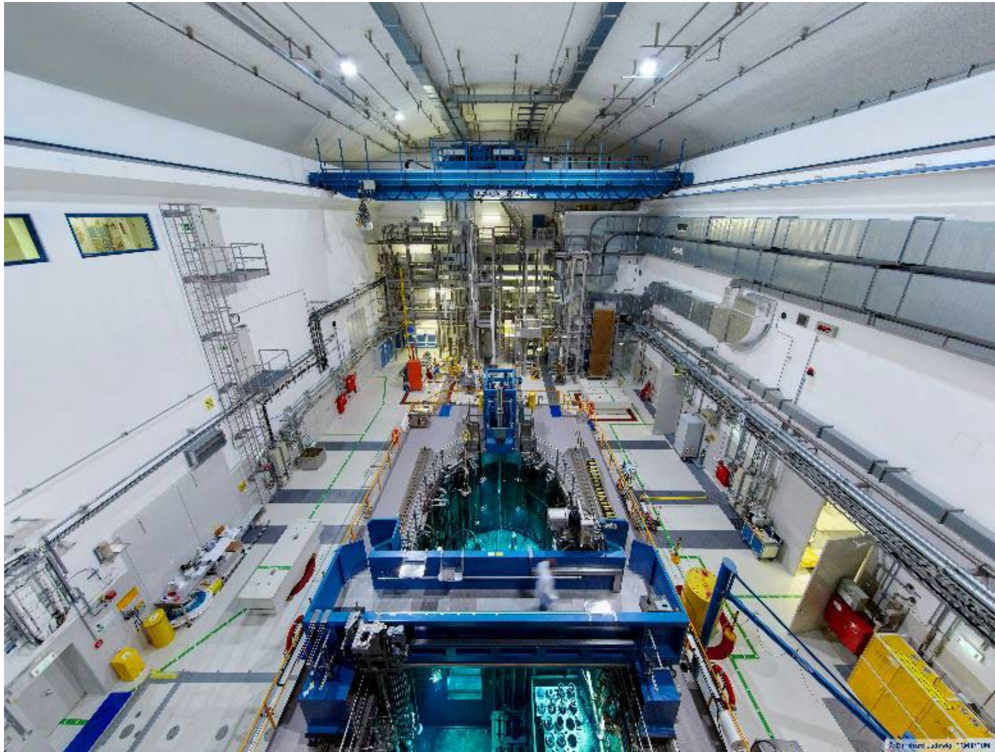
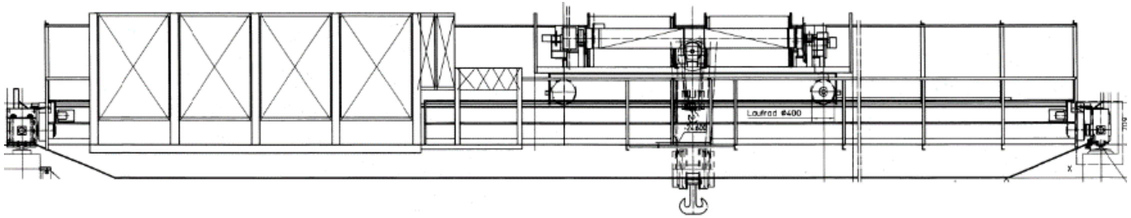
Introduction and Overview

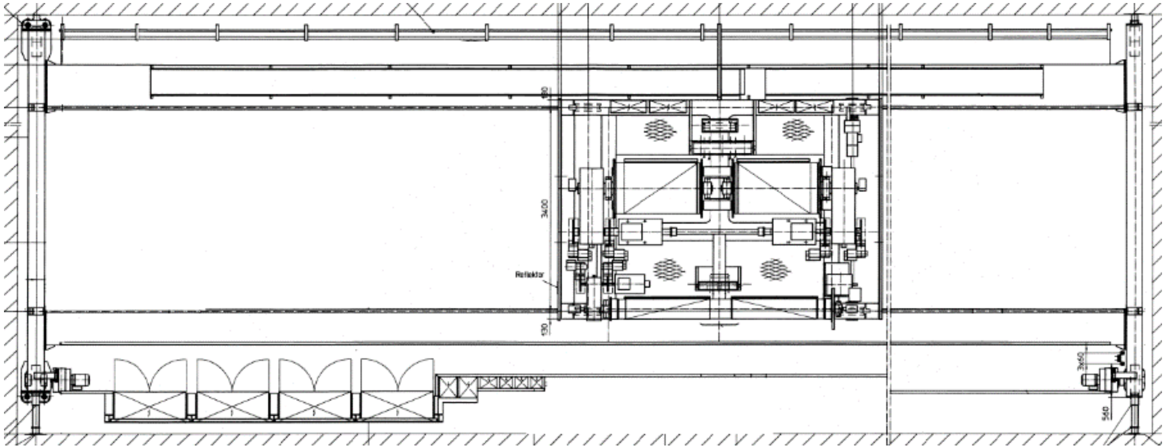
- Research Neutron Source FRM II at Technical University of Munich in operation since 2004
- Most of the systems installed in late 1990s
- Crane in the reactor hall is one of the most vital systems



Introduction and Overview

- Double girder overhead crane with two hoists (3.2 t and 20 t)
- Used for transports within and into reactor hall and reactor pool
- Most important applications:
  - Main hoist 20 t: handling of storage containers for high-level nuclear waste
  - Auxiliary hoist 3.2 t: handling of fuel elements





Introduction and Overview

- Crane is in operation for more than 25 years:
  - Obsolete control system
  - Maintenance effort is increasing
  - More and more defective components → identical spare parts not available since most components have been discontinued and inventory stocks have been depleted → components need to be replaced with similar or successor components → extensive documentation, testing, and verification work

- Changes to the German nuclear safety standards (KTA) require extensive modifications to the crane's control system

➔ Estimation that replacement of whole electrical and control system is more time and cost effective than continuous repairs and application of necessary modifications
➔ More details at Proceedings of IGORR 2023

Introduction and Overview

- Completely new, state of the art control system installed

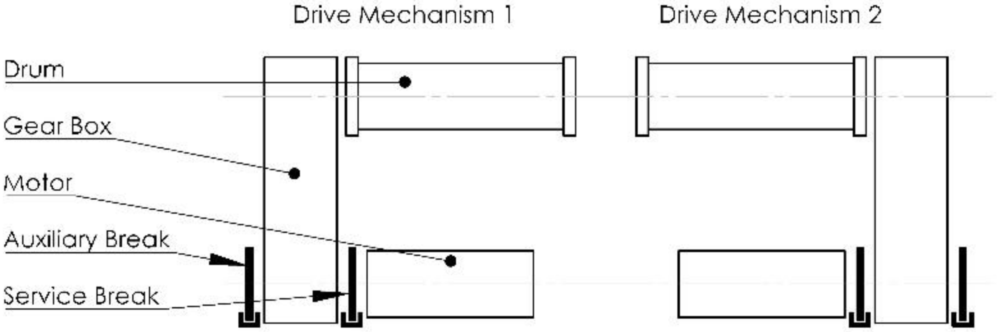
- Core components: two independent PLCs, an operational PLC and a safety-related PLC
  - Operational PLC: responsible for all standard control functions of the crane
  - Safety PLC: Monitoring the operational PLC and all other components and parameters

- German nuclear safety regulation require test of hoist brakes → tests include measuring of reaction times and braking times and comparison of measurements to calculated target values

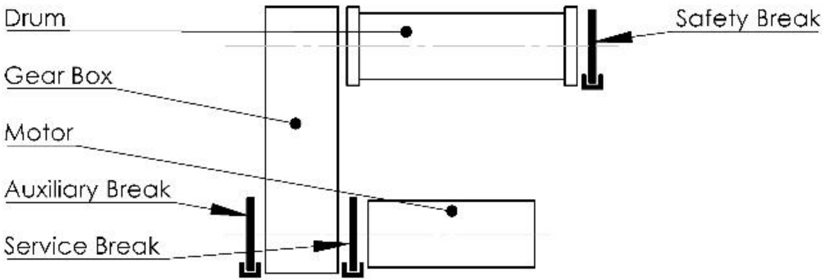
- Not possible to perform these recordings with old control system → measurements were conducted for the first time during SAT of modernization

Design of Hoists

- 20 t main hoist
  - Double drive mechanism chain
  - One service break and one auxiliary break on each side



- 3.2 t auxiliary hoist
  - Singe drive mechanism chain
  - One service break and one auxiliary break
  - Safety break on drum (→ engages only in case of gear box failure)



Function of Hoist Brakes

- Deceleration is performed electrically via frequency converter
- Brakes usually only act as holding brakes → engage only after hoist has come to a stop
- Only in case of malfunction or failure, brakes engage during hoisting motion:
  - If all brakes engage, transmitted forces must not exceed limitations of gearbox and other components
  - If brakes fail, a single brake must be able to decelerate and hold the load

→Every brake must be sufficiently strong to decelerate the maximum permissible load from maximum speed, but not so strong that all brakes together induce impermissibly high forces on the gearbox or other components

→Based on braking forces, expected braking times were calculated

Brake Testing

- Maximum load (3.2 t / 20 t) is lowered at maximum speed
- Test command issued: frequency converters are abruptly switched off (→ cannot contribute to braking effect) and brakes are activated
- Test done for all brakes together, various combination of two brakes, and each brake individually

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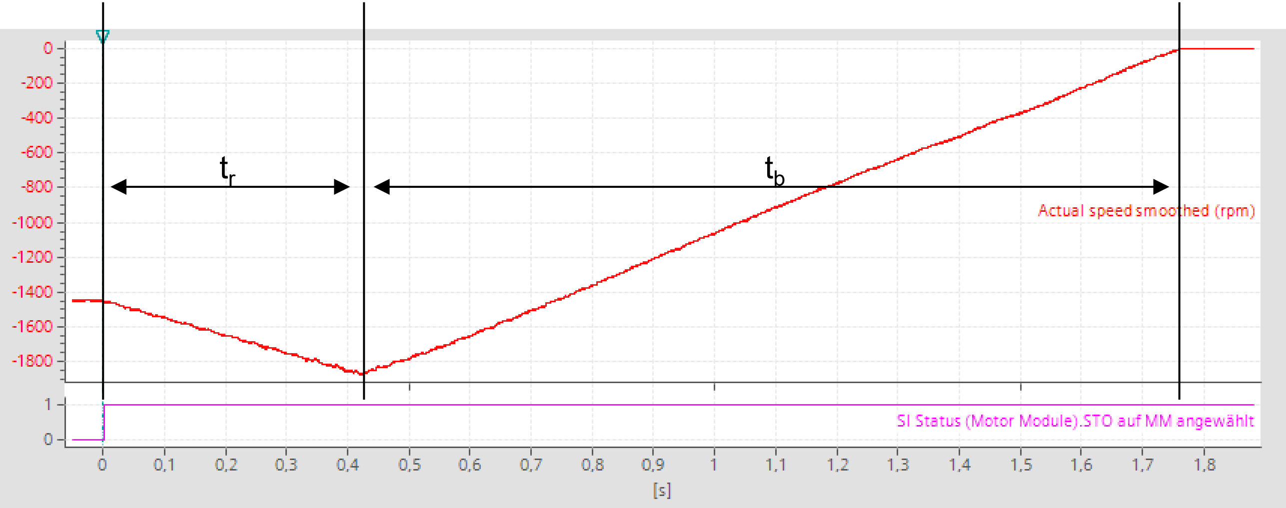
Brake Testing - Example

- t < 0 s: moves downwards at maximum, constant speed (≈ 1450 rpm)
- t = 0 s: test command issued → frequency converter shuts down (almost) immediately, brakes require a certain time (≈ 0.42 s) to engage → acceleration of load (to ≈ 1875 rpm)
- t > 0.42 s: braking effect
- Standstill ≈ 1.35 s after brakes engaged

- Reaction time t_r: from issuing test command (t = 0 s) to begin braking (t ≈ 0.42 s)
- Braking time t_b: from begin braking (t ≈ 0.42 s) to standstill (t ≈ 1.77 s)



Comparison of Measured and Expected Values

Brake	Reaction Time t_r / s		Braking Time t_b / s	
	Target Value	Measured Value	Target Value	Measured Value
Service Break	0.20	0.47	1.16	0.32
Auxiliary Brake	0.20	0.48	1.16	0.43
Safety Brake	0.45	0.26	1.10	1.65
Service & Auxiliary Brake	missing	0.49	missing	0.18

- Deviations between specification and calculation for braking times
- Incomplete specifications

Calculation of Breaking Torque - Approximation

- “Reverse” approach: Calculating braking torques based on measured reaction and braking time

- Brakes (braking torque M_B) must hold the load (holding torque M_H) and decelerate the moment of inertia J, with η representing losses and ω representing angular velocity

$$M_B = \frac{M_H + J\,\frac{d\omega}{dt}}{1+\eta}$$

- $\frac{d\omega}{dt}$ can be approximated using the difference quotient $\frac{\Delta n}{\Delta t}$ during the braking time

$$M_B = \frac{M_H + J \cdot 2\pi \cdot \frac{\Delta n}{\Delta t}}{1+\eta}$$

Calculation of Breaking Torque - Approximation

- Moment of inertia J can be approximated form the behavior during free fall (= during reaction time)

$$J = (1-\eta) \cdot M_H \cdot \frac{1}{2\pi \cdot \frac{\Delta n}{\Delta t}}$$

- Holding torque M_H is necessary to calculate M_B and J
  At standstill brakes must hold load m_L and weight of crane rope, hook, etc. m_S via hoisting drum with radius r, conversion with rope factor i_S and gear ratio i_G

$$M_H = \frac{1}{i_S} \cdot \frac{1}{i_G} \cdot (m_L + m_S) \cdot g \cdot r$$

Calculation of Breaking Torque - Approximation

Results of approximation:

	M_B specification	M_B calculated
3.2 t Auxiliary Hoist	85 Nm	250 Nm
20 t Main Hoist	216 Nm	550 Nm

- Deviations between specification and calculation
- Discrepancy between actual and target values for braking times is also reflected in braking torques

Calculation of Breaking Torque - Detailed Calculation

- More detailed calculation of actual breaking torques was performed according to German Standard (DIN 15434-1)

- Instead of previously shown “reverse” approach, calculation was based on actual mechanical configuration, including mass moments of inertia, gearbox design, real friction coefficients, etc.

- Results:
  - Actual braking torque 20 t main hoist: lower than estimation of approximate approach, but still higher than specification
  - Actual braking torque 3.2 t auxiliary hoist: higher than estimation of approximate approach → additionally load on gearbox was 10-15% above original design specification → as a result recalculation of gearbox was necessary → application of slightly modified yet still conservative safety factors showed that the load remained within permissible range

Adjustment of Braking Torques

- Goal: reduce braking torques to specified range

- 20 t main hoist: goal could be easily archived by reducing the spring preload

- 3.2 t auxiliary hoist:
  - 1st approach: reduction of spring preload lead to reduced braking torque (= increased braking time), but also to increased reaction time (=higher overspeed during free fall → speed exceeded design limit)
  - 2nd approach:
    - Different springs: braking torque could be significantly reduced
    - New brake solenoid: necessary with new springs, but still too long reaction time
  - 3rd approach: adjustment of solenoid and its control circuit (rapid demagnetization): targeted reaction time achieved

Summary

- After refurbishment of crane: First-time measurement of hoist brake reaction time and braking times as per German nuclear standards

- Significant deviations between specifications and actual values for both hoist
- Braking times too short → braking torques exceeded limits

- Actual braking torque approximated and recalculated based on mechanical setup

- Mechanical brake modifications (springs, solenoid) lead to specified braking times
- Initial issues with long reaction time and overspeed solved

- Final braking behavior within specified limits

Thank you for your attention!