SOLUTIONS FOR EVALUATING THE DURATION OF TRANSIENT PERIODS FOR GANTRY BRIDGES

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Abstract - Cranes are complex installations, equipped with one or more mechanisms corresponding to the movement of loads. The movement of moving loads may be a compound movement performed by several mechanisms, depending on the type of crane. For overhead travelling cranes these movements can be composed of the translation movement along the travel path, the translation movement of the load trolley along the main girder. When the travel path has considerable distances, the plant moves at maximum speed for which rapid acceleration and braking are required. During these periods, the load-bearing structure is additionally subjected to stresses occurring during transient periods, i.e. tangential inertia forces, vibrations, etc. If the time between transient periods is short in relation to the duration of occurrence, the consecutive stresses overlap and may affect the safe operation of the crane. This paper presents a practical approach to determine the duration of these transient periods, in particular braking, by using mechatronic devices that utilize ultrasonic or infrared sensors or using video analysis of motion trajectories. These assistance systems will enable the further introduction of AI artificial intelligence in the monitoring of crane transient regimes.

Keywords: Cranes, Mechatronic system, Ultrasonic sensors, Infrared sensors, Video analysis.

1. Introduction

Overhead travelling cranes are lifting installations belonging to the group of travelling cranes, having the possibility of realizing all working movements by mutually perpendicular translations, thus the lifting device has access to any point of a volume on the platform. In comparison with construction jib cranes, which have a constant capable moment, travelling cranes have the ability to lift and move the nominal load throughout the working space of the hoist.

Lifting machines are characterized by an intermittent cyclic operation with large variations of the mechanism parameters. The phases of an operating cycle for each mechanism consist of a starting period, a steady-state period and a braking period. The transient periods of the mechanisms are the starting and braking periods are particularly important in crane safety analysis [1].

When the track has considerable distances, the installation is moving at maximum speed for which rapid acceleration and braking are required. During these periods, the load-bearing structure is additionally loaded by stresses that during transient periods, i.e. tangential inertia forces, vibrations, etc [2].

Nowadays, in the practice of designing hoisting installation mechanisms, asynchronous electric motors with short-circuited rotors, powered by a frequency converter connected to a three-phase mains supply, are frequently used. In these solutions, the speed of the motor is varied by varying the power supply frequency, resulting in a continuous variation of the speeds or microspeeds required for assembly operations in construction.

The analytical determination of the duration of the transient regimes aims to verify the ability of the driving motor of the translation mechanism and the brake to start and brake within a reasonable period of time, respectively, and to check their dimensioning. The study of the braking regime is important in maintaining the stability of the load hooked in the hook during braking and especially when the travel mechanisms reach the end of their stroke. The algorithm for calculating the duration of

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braking periods for the displacement mechanisms presented in the following lines is mentioned in the literature [3].

The purpose of the transient braking regime analysis is to check the ability of the brakes to brake within a reasonable period of time if the stop is sudden or jerky. During this period, the moving masses are decelerated from the steady speed to a lower speed or to a stop. The dynamic steady state equation is that in relation (1).

$$M_f + M_s = M_d \quad (1)$$

In which: M_f - braking torque; M_d - inertia forces torque; M_s - torque of the static resistances reduced on the shaft of the driving motor.

The braking time in the case of traveling mechanisms for cranes in the crane craneway can be determined analytically using the following relationship:

$$t_f = \frac{1}{M_f + M_s}\left[9{,}55\frac{(Q+M)v^2}{n}\eta + \frac{1{,}2n}{38{,}2}\sum MD_m^2\right] \quad (2)$$

Where: Q - load hooked in the crane hook; M - mass of the load carriage; v - speed of the travel motion; n - speed of the electric drive motor; η - kinematic chain efficiency of the travel mechanism; $\sum MD_m^2$ - cumulative flywheel moment of the machine parts on the axis of the drive motor.

The assessment of the braking time for existing cranes in operation using relation (2) requires a lot of constructive information about the crane under analysis as well as about the travel mechanism of its trolley. It is quite difficult to define the magnitudes in the braking time calculation relation which makes it difficult to use. For this reason, we had to identify an alternative solution to estimate the braking time for overhead cranes in operation, which is presented in the paper.

Factors that influence the braking efficiency of overhead cranes can be: load mass - larger loads require stronger braking systems; crane type - overhead, tower, and self-propelled cranes require different braking solutions; frequency of use - different braking systems are required for heavy use versus occasional use; operating conditions - such as high humidity, extreme temperature or dusty environments can affect brake performance. The use of artificial intelligence AI to analyze crane braking is an emerging direction in mechanical engineering and industrial automation. Although scientific studies are still in their infancy, the implementation of AI technologies in monitoring and optimizing crane braking systems can bring multiple benefits.

2. Method and Materials

The research was carried out in the laboratory of lifting machines of the Faculty of Mechanical Engineering and Robotics in Construction - UTCB, using the laboratory stand - bridge crane. The laboratory stand - overhead crane is equipped with the main beam on which the load carriage travels along it with the help of a travel mechanism driven by a three-phase electric motor, Fig.1. The travel of the load carriage is limited in the area of the stroke ends by means of the T2 trigger, in which case the regime travel speed is reduced when approaching the stroke limit and the T1 stop when the power supply to the motor driving the travel mechanism of the load carriage at the end of the beam is stopped. The study aims to develop alternative solutions that can be installed on existing overhead travelling cranes and that can monitor the transient braking regime in the translational movement of the load trolley and also for the situation of braking at the end of the stroke. In the article we present the analysis of the transient braking regime at the end of the stroke for the load trolley, in the case of the laboratory stand, which was realized by means of the following methods:

- ➢ Using a monitoring system, labeled SM in Fig.1, which uses an ultrasonic sensor to determine distances;
- ➢ Using a monitoring system, labeled SM in Fig.1, which uses an infrared sensor to determine distances;
- ➢ Video analysis using translational motion video and subsequent video tracker software.

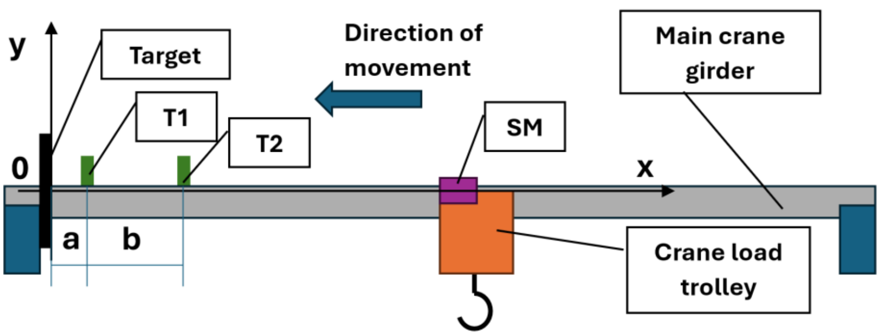

Figure 1: Schematic of the overhead crane test stand

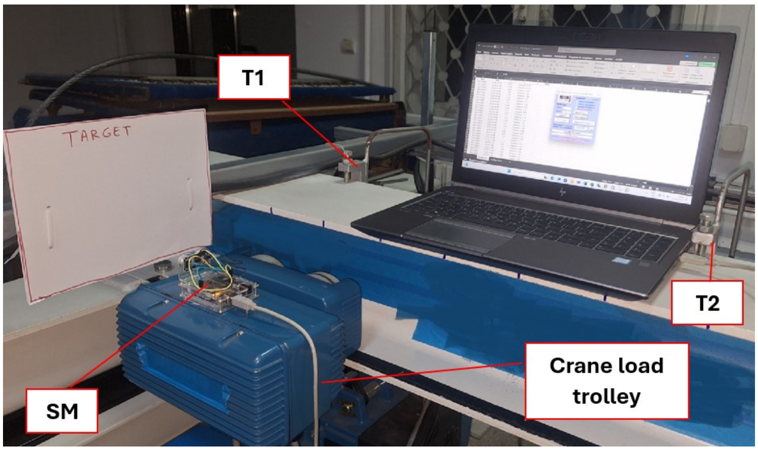

Figure 2: Test stand

The analysis of the transient braking regime involved the following steps: positioning the load trolley on the main beam at a distance of about 180 cm from the end of the stroke; operating the trolley's motor in the direction of its movement towards the end of the stroke, see fig.1; recording the results collected from the sensor; videotaping the translation movement; interpreting the results. The tests were performed using the overhead crane laboratory stand, with no load in the hoist hook, T2 trigger mounted at distance b= 55 cm, T1 stop mounted at distance a = 7 cm, at the end of the stroke a flat white surface was mounted, see fig.1 and fig.2.

For the monitoring system, labeled SM in fig.1, we used the component connection diagram in fig.3. In the diagram we identify the following components: 1 - distance sensor; 2 - Arduino Uno; 3 - computer for data collection.

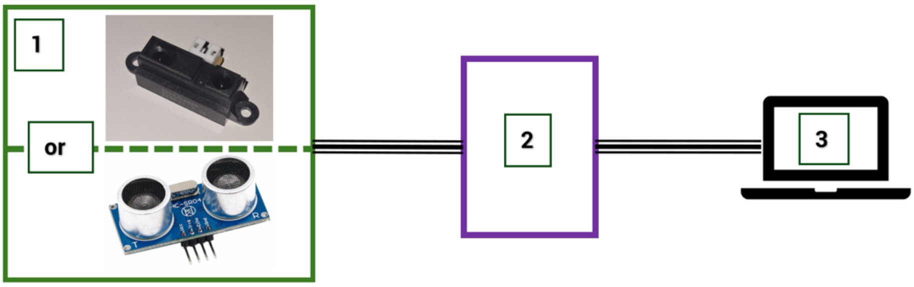

Figure 3: Schematic of the monitoring system

For the sensor component we have used distance determination devices that have different working principles. In the tests we used affordable, simple to use and implement components such as:

The HC-SR04 ultrasonic sensor which is a distance measuring sensor that has a range from 2 cm to 400 cm [4,5]. The sensor is composed of two ultrasonic transducers. One is the transmitter that emits ultrasonic sound pulses and the other is the receiver that receives the reflected waves. The specifications of the sensor are: Operating voltage 5V DC; Operating current 15mA; Operating frequency 40KHz; Operating range from 2 cm to 400 cm; Accuracy 3mm; Measuring angle less than 15°; Size 45 x 20 x 15mm. The sensor emits an ultrasound at 40 000 Hz which travels through the air and if there is an object or obstacle in its path, it will bounce back to the sensor. Given the travel time and the speed of sound, we can calculate the distance [6]. Ultrasonic sensor has the advantage that it is good for precise measurements on large areas; works well on flat and hard surfaces; easy to use with Arduino microcontroller [12,13]. The ultrasonic sensor has problems with soft or inclined surfaces that do not reflect sound well and can be influenced by air temperature and humidity. The mechatronic system using the ultrasonic sensor is shown in Fig. 4.

The Sharp GP2Y0A41SK0F IR infrared sensor is a distance measuring sensor that has a range from 2 cm to 400 cm. Measured distance: between 10 cm and 80 cm; Sensor specifications are: Power supply voltage: 4.5 V - 5.5 V; Power consumption: 30 mA; Output type: analog; Refresh rate: 38 ± 10 ms; Package size: 29.5×13×13.5 mm [7,8]. IR sensors work by using a specific light sensor to detect a selected wavelength of light in the infrared (IR) spectrum. The Sharp IR sensor works by the triangulation process. A pulse of light (with a wavelength of 850nm +/-70nm) is emitted and then reflected back (or not reflected at all) [9]. When the light returns, it returns at an angle that depends on the distance of the reflected object. Triangulation works by detecting this angle of the reflected beam - by knowing the angle, the distance can be determined.

The Sharp IR sensor applies a modulated frequency to the emitted IR beam. This method of distance determination is not influenced by ambient light interference and the color of the detected object.

A disadvantage of this type of sensor is the beam width. Unlike the ultrasonic sensor, the IR beam is quite thin - which means that in order to detect an object, the sensor must be pointed directly at that object. The Sharp IR sensor has a nonlinear output, this means that as the distance increases linearly the analog output varies nonlinearly.

Figure 4: SM monitoring system - left with IR sensor and right with ultrasonic sensor

The video analysis involved the realization of some video recordings that were taken with the Canon EOS M50 II camera mounted on a tripod placed about 250 cm from the test stand - overhead crane. The movies taken during the tests were decomposed into sub-sequences corresponding to the braking regime at the head of the race using a video editor. The subsequences were analyzed with Traker software [10] to evaluate the trajectory, displacements, speed, acceleration.

In the paper we present the results obtained from the video analysis of the load trolley moving from the position about 120 cm from the end of stroke. During the movement of the trolley, the speed reduction limiter T2 is actuated in the first phase and later the stroke head limiter T1 is actuated to stop the translation movement, Fig. 5. Following the video analysis, we have obtained in the case of the movement of the load trolley, displacement in the x-direction, respectively speed in the x-direction, fig. 5.

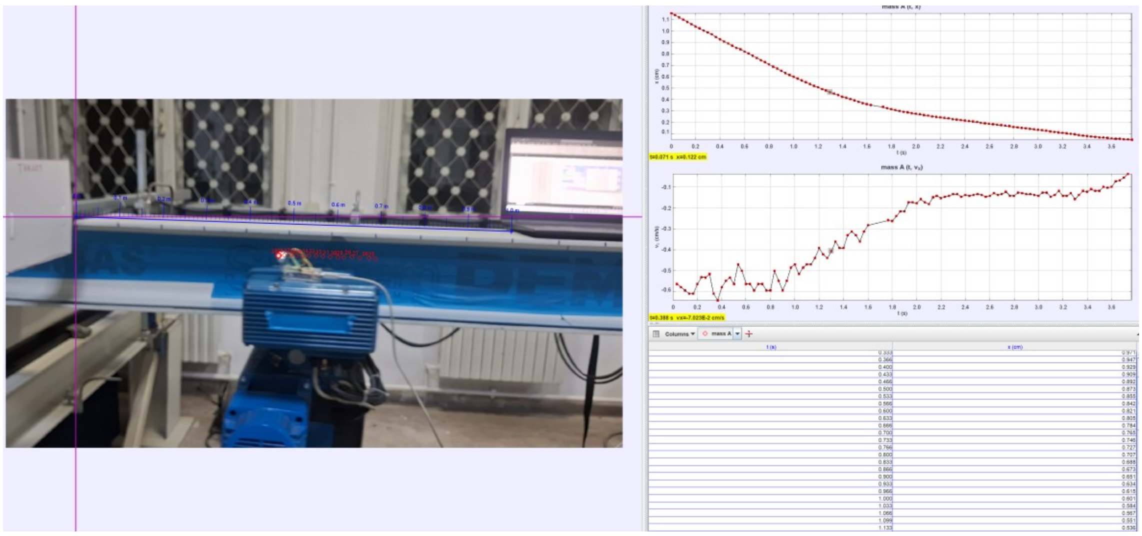

Figure 5: Video analysis of the translational motion of the load trolley

3. Results

The determination of the displacement distance during the movement of the load trolley towards the end of the stroke was carried out on the basis of a series of tests. The first tests carried out were those of calibration of the measurement system. The measured values were registered in a database using the Excel Parallax Data Acquisition tool PLX-DAQ-v2.11[11].

In this database we registered ten tests using the ultrasonic sensor and ten using the IR sensor for the assessment of the distance during the displacement of the load trolley. The average of the values obtained with the ultrasonic sensor are presented in the diagram in fig.6. The average of the values obtained with the IR sensor are presented in the diagram in fig.7. The results obtained from the video analysis are presented in the diagram in fig.8.

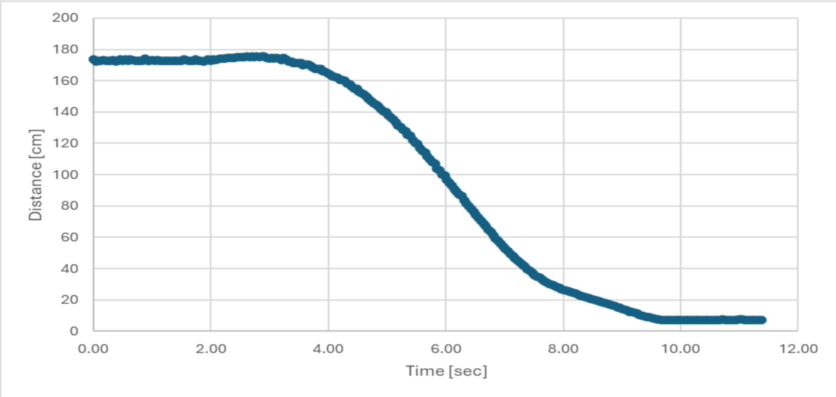

Figure 6: Variation of distance over time for ultrasonic sensor

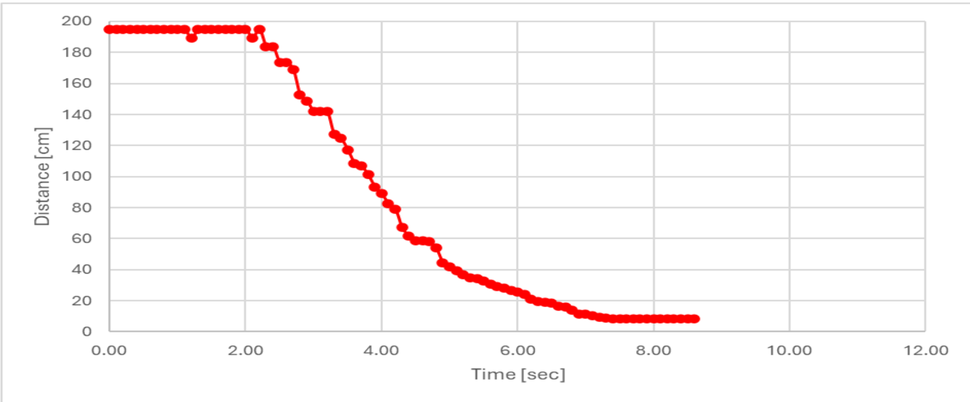

Figure 7: Variation of distance over time for SHARP sensor

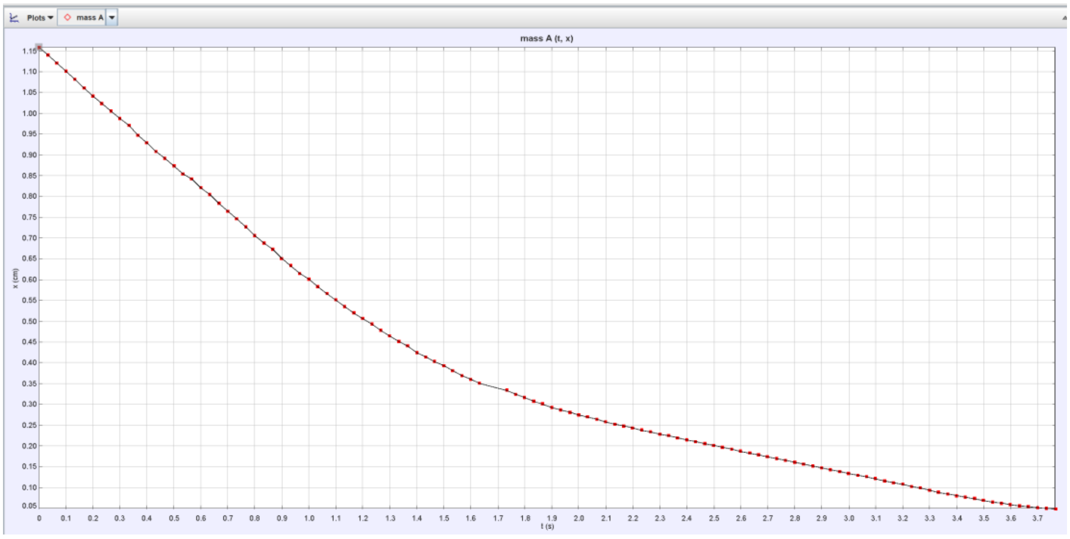

Figure 8: Variation of distance over time for video analysis

In order to compare the results between the video analysis of the actual movements and the recordings obtained in the case of the ultrasonic and IR sensor tests, we have superimposed in Fig.9 the variation of the measured distances over time for the three methods used in the analysis of the load trolley movement from the 120 cm position to the end of the stroke on the main beam. Interpreting the data presented in Fig.9 we find that the plots of the variation of the distance over time show a similar, almost overlapping variation trend in the case of the video analysis and the ultrasonic sensor. In the case of the infrared sensor we observe a time lag which we consider to have been caused by faulty calibration, considering the nonlinear characteristic of the sensor. If the speed of the overhead crane is high video tracking analysis is a good method, if the speed is low and we do not need high accuracy the infrared sensor is suitable, if an affordable and easy to implement solution is desired the ultrasonic sensor is an accepted solution.

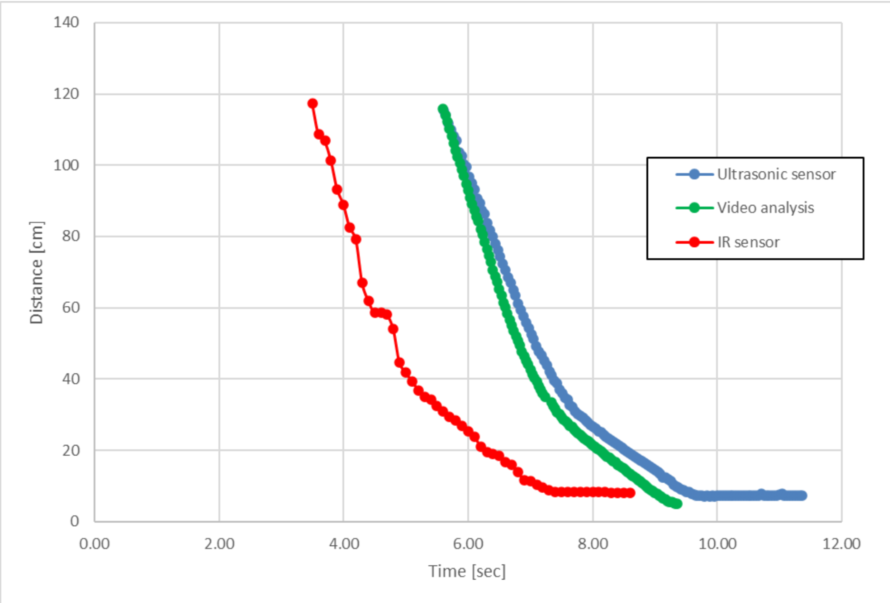

Figure 9: Comparison of distance variation over time for the three methods

4. Conclusions

Cranes are widely used for lifting and moving heavy objects in dynamic environments where operators coexist. The sudden appearance of workers, vehicles can affect crane safety. To avoid possible collisions, cranes must have predictive capability to know how dangerous the situation is. In this paper we presented an attempt to solve the safety problems of overhead cranes. The presented experiments, using a laboratory stand identical to a real overhead crane, demonstrate that the proposed methods of braking distance evaluation are useful for safe braking control of overhead cranes. The three methods can be used in relation to the specificity, importance and working environment of the overhead crane to be monitored. The obtained results may represent a first step in the implementation of artificial intelligence (AI) in crane braking analysis. The implementation of AI technologies in the monitoring and optimization of crane braking systems can bring multiple benefits in their use.

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