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Development of a New System for Precise Measurement of the Weight of Valuable Liquid Metals with Ladle Cranes

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Abstract: Precise measurement of liquid minerals (chrome, brass and iron) under high temperature values during transportation with a ladle crane is a very important and critical process for semi-finished product production. In this study, the technological integration and optimization of liquid mines in a ladle crane design is examined and focused on examining the design principles, mechanism and engineering approaches that need to be developed. Also, high precision weighing can be made by means of the load cell technology. In the design step, material selection, integration and mechanical structure optimization are discussed. It has been determined that the design of the ladle crane will adapt to environmental effects and operational requirements. A series of tests were performed to evaluate the weight measurement performance of the ladle crane. As a result, the principles of precision weight measuring ladle crane design, engineering approaches and test results revealed that the developed system is very effective and reliable.

Keywords: Ladle crane, Precision weight measurement, Design and manufacturing

Introduction

In contemporary industrial applications, particularly those involving the handling of precious molten metals that require precise weighing and processing under high-temperature conditions, the operations of transportation play a crucial role in terms of efficiency, safety, and precision (Stein, 1964). During the execution of such operations, fundamental features such as high transport capacity, the ability to operate under high-temperature conditions, and precise weighing capabilities emerge as critical factors influencing the successful implementation of industrial processes (Bertodo, 1959). In this context, modern engineering approaches and technologies enable the development of ladle crane systems tailored to the type of molten metals to be processed and operational requirements (Ye et al., 2023). Industrial operations are becoming increasingly complex (Hofstotter, 1982), and the handling and processing of molten metals that require precise measurement are among the most intensive areas where industrial operations are applied (Meyer, 1973). It is precisely at this point that the importance of ladle crane design comes to the forefront. The high transport capacity and advancements in ladle crane design have been observed to enable the safer and more effective execution of such challenging operations, thanks to their technical specifications (Oi, 1986).

The design of a ladle crane should encompass not only the ability to transport the ladle but also features such as the ability to operate under high temperatures, precise weighing capability, and remote control (Wu et al., 1981; (Dorsey, 1964; Qiong et al., 2007). The ability of the ladle crane to operate under high temperatures provides operational flexibility in industrial environments where molten metals are processed at high temperatures (Stano et al., 2020). This, in turn, serves a critical function in enhancing both efficiency and ensuring operator safety (Bagaria & Sharpe, 1974). Precise weighing capability emphasizes the ladle crane's ability to accurately measure and process molten metals (Hoffmann, 1979). Load cell technology enhances operational accuracy by offering high-precision weighing capabilities (Hoffmann, 2012). This, in turn, ensures cost savings in industrial processes while guaranteeing the accurate processing of molten metals (Lindorf, 1968).

On the other hand, the feature of remote control used in ladle crane design enables operators to safely control the crane (Mandai et al., 1990). This enhances operational flexibility and keeps operators away from hazardous conditions. This study also includes experimental work to objectively evaluate the performance of the designed ladle crane system (Zhang et al., 2022). These experimental studies are based on measuring the very small analog signals from the Wheatstone bridge circuit outputs of load cells to measure their accuracy when loaded and unloaded (Takezawa et al., 2010). With four load cells placed on the lifting group frames, the ladle is accurately weighed in both the lowest and highest hook positions independently of rope angles and friction losses between the rope and the pulley (Hu et al., 2023). The integration of modern engineering principles and technologies contributes to the industrial operations through ladle crane systems (Gee, 1984).

This study focuses on emphasizing the importance of ladle crane design in industrial applications and innovative solutions developed to meet specific requirements. To achieve this, the study ensures a safe working environment for operators by keeping them away from the work area while carrying out the process of transporting valuable molten metals. Subsequently, potential losses of precious molten metals during the operation are eliminated by positioning four load cells in appropriate locations.

Experimental Study

In this section, two separate test methods were used to measure the electrical signals produced under variable loads by the load cells that enable precise weighing of heavy metal-carrying ladle cranes. The signal generation behavior of the load cell in the vertical direction is called Experiment-1, and the signal behavior of the load cell in the horizontal direction in addition to the loads in the vertical direction has been called Experiment-2. In this study, an experimental setup was established using a 200 ton press, multi-meter, adjustable power supply, wireless weighing indicator and load cell. In this experimental setup, variable loads were applied to the load cell with a 200 ton press, and the amount of these applied loads was made readable on the screen with the weighing indicator. After applying the desired amount of load, the electrical signals produced by the load cell were measured with the help of a multi-meter and the data has been recorded.

Load Cell Technical Specifications

In the experiments carried out throughout the study, the "HSC-40t-V C3" model of the brand named "ESİT" has been used. The loadcell used in the experiments is fed by an adjustable power supply. The position and label information of the load cell were shown in Figure 1. Additionally, the technical specifications of this load cell are given in Table 1.

Figure 1. Loadcell model data

Table 1. Load cell technical specifications

Maximum capacity (Emax)	**kg**	**40000**
Minimum measuring range (Vmin)		Emax/6750
Total error	%	≤±0.05 ≤ ±0.02 ≤±0.015
Return to zero error (DR)	%Emax	0.0039 0.0030
Overloading capacity	%Emax	150
Extreme side loading capacity	%Emax	100
Breaking capacity	%Emax	300
Stretch (Emaxyukte)	mm	≤ 0.3
Maximum excitation voltage (Umax)	V	15
Earning (Cn)	mV/V	2 ±0.1%
No-load output	%Cn	≤±1.0
Input resistance	Ω	385 ±20
Output resistance	Ω	351 ±3
Insulation resistance	MΩ	≥500
Corrected operating temperature range	°C	-10...+40
Operating temperature range	°C	-40...+80

The Behavior of Load cell Signal in Vertical Direction

While the ladle crane carries out the transportation operations of precious molten metals, it also performs this process with precise weighing and ensures operational accuracy. A load cell experimental setup has been established to ensure that the weighing process was carried out precisely and accurately. In this experimental setup, the vertical signal generation behavior of the load cell was examined under the title Experiment-1. This experimental setup is shown in Figure 2 and then the experiments have been carried out. The purpose of this experiment is to monitor the electrical signal behavior produced by the load cell against vertical loads and to determine how sensitive and stable a signal it produces by evaluating the results. First, the load cell has been connected to an adjustable power supply and the supply voltage was set to 4.5 V. Then, a number of loads were applied to the load cell in the vertical direction using a 200-ton press, not exceeding the capacity of the loadcell. When each load was applied, the amount of the applied load has been displayed with the wireless weighing indicator. When the desired load amount has been reached, the value of the electrical signal produced by the load cell in mV was measured with a multi-meter.

Figure 2. Experimental system for load measurement of molten metal transport ladle

The Behavior of Load Cell in the Horizontal Direction in Addition to Vertical Loads

In Experiment-1, the electrical signal output values produced by the load cell against vertical loads were observed in mV. In this study, the signal behavior of the load cell in the horizontal direction, in addition to the vertical loads, was examined under the title Experiment-2. In Experiment-2, in addition to the vertical loads applied to the load cell, a horizontal load was also applied simultaneously, as seen in Figure 3. Under these conditions, the signal stability produced by the load cell was examined. For Experiment-2, in addition to the mechanism used in Experiment-1, a hydraulic press with a manometer attached to the end was added to apply horizontal load. With this added hydraulic press, a horizontal load was applied to the load cell. In this experiment, first the adjustable power supply was connected to the load cell and the supply voltage was set to 4.5 V. Since the supply voltage was kept the same in both experiments, a more accurate comparison was made and the differences were seen more clearly. Then, loads were applied simultaneously in vertical and horizontal directions, and the amount of load applied in the vertical direction was displayed on the wireless weighing indicator, while the loads in the horizontal direction has been displayed via the manometer in the hydraulic press. After the required tests were performed, it has been seen and confirmed that the 25 bar value on the manometer corresponded to approximately 1 ton. Thus, the amount of load applied in the horizontal direction has been adjusted to the desired amount. Then, after applying the desired amount of load in horizontal and vertical directions, the electrical signal outputs produced by the load cell has been measured in mV with a multi-meter. Table 2 has been shown the signal outputs versus the load amounts obtained in the vertical direction.

Figure 3. The application of vertical and horizontal loading

Results and Discussion

In this section, all results regarding the signal output values obtained from the load tests performed on the load cell have been examined and evaluated. In Table 2, the output values of the electrical signal produced against the loads applied vertically to the load cell are given in mV.

Table 2. The mV values based on the vertical loading conditions

Vertical load (kg)	Signal output value (mV)
0	0
1054	0.3
2989	0.7
5038	1.1
10207	2.3
15085	3.4
20202	4.6
30000	6.8
40000	9.1

As seen in Table 2, variable loads were applied in the vertical direction, not exceeding the carrying capacity of the load cell. When we examined the electrical signal output values produced by the load cell against these loads, it has been seen that it did not produce a signal in the no-load state. Afterward, when a load of approximately 1 ton was applied vertically to the load cell, it has been observed that it produced a signal of 0.3 mV. Apart from 1 ton, the results in Table 2 have been obtained after applying a vertical load of approximately 3, 5, 10, 15, 20, 30, and 40 tons respectively with the press. Considering these results, it has been observed that as the amount of applied load increases, the electrical signal output value produced by the load cell increases at the same rate. When the data obtained was evaluated, it was observed that the rate of increase of the signal output value was directly proportional to the amount of applied load. Table 3 contains the electrical signal output values produced by the load cell against the loads applied simultaneously in the horizontal direction while the load is applied to the load cell in the vertical direction.

Table 3. The mV values based on the vertical and horizontal loading conditions

Vertical load (t)	Horizontal load (t)	Signal output value (mV)
5.4	0	1.2
5.4	1	1.2
10.4	0	2.4
10.4	1	2.4
10.4	2	2.4
19.8	0	4.5
19.8	1	4.5
19.8	2	4.4
19.8	3	4.3
19.8	4	4.5
40	0	9.1
40	1	9.1
40	2	9.1
40	3	9.2
40	4	9.1
40	5	9.1
40	6	9.2
40	7	9.2
40	8	9.0

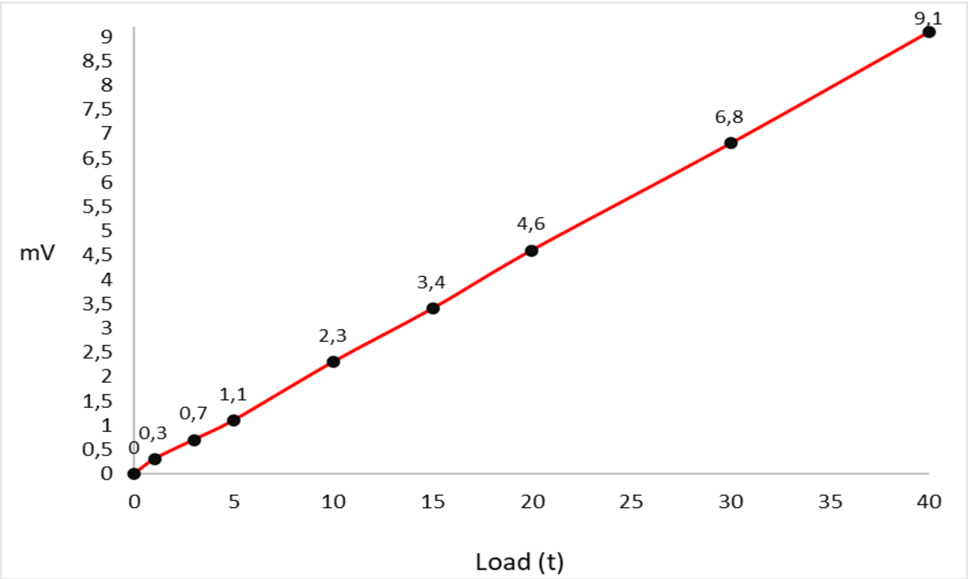

Figure 4. The signal production behavior of the load cell under load

As shown in Table 3, variable loads were applied to the load cell in both the vertical and horizontal directions without exceeding its carrying capacity. Initially, vertical loads were applied using a press without any horizontal load, and the signal output values in Table 3 were obtained. Subsequently, while applying vertical loads, horizontal loads were gradually applied using a hydraulic press, and the signals generated by the load cell were measured in millivolts (mV) using a multi-meter to obtain the signal output values in Table 3. When evaluating the obtained results, it was observed that the load cell maintained its signal stability even when subjected to variable horizontal loads while under a vertical load, and it was not affected by this condition.

As seen in Figure 4, a signal generation behavior chart of the load cell under load was created with the data obtained from the test results in Table 2 and Table 3. When we examine the graph in Figure 4, it is seen that the mV curve increases linearly. It has been observed that the linear increase in the graph in Figure 4 is due to the direct proportion between the amount of load applied to the load cell and the electrical signal output values obtained using the multi-meter.

Conclusions

In this study, the signal output values produced by the load cell capable of precise weighing under variable loads applied in vertical and horizontal directions were examined with two different experimental methods. The conclusions reached in the light of the results and evaluations obtained from these experiments can be summarized as follows:

- Since the electrical signal output value produced by the load cell used in the experiments increases or decreases linearly, it has been shown that it can weigh with gram precision.
- While vertical load is applied to the load cell, it also prevents possible load losses as it maintains its signal stability despite being exposed to horizontal load.
- When we look at the results obtained from the experiments, this result creates a linear graph since there is a direct proportion between the load change rate applied to the load cell and the signal output value rate produced by the load cell. The linearity of the graph facilitates the conversion of the produced analog signals into digital signals. Thus, the tonnage data of the load cell used in the experiment was easily read.
- It can be seen from Experiment 1 and Experiment 2, it was observed that the load cell produced a signal with maximum accuracy when the load cell operated in the appropriate operating temperature range and was positioned on a fixed plane.
- As a result of the application of the load cell used on the crane and capable of precise weighing, this study increased the efficiency of the processing operations of precious molten metals and allowed accurate weighing.

Recommendations

In future trends, the weight of precious molten metals will be measured with sensitive load cells. In this way, gram-accurate weighing will be possible by preventing load losses that may occur during the weighing of precious molten metals.

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