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Automated Contactless Linear Measurement of Front Axle Beam

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Abstract - *This paper presents the validation of a proposed automation system for contactless linear measurement of a Front Axle Beam (F.A.B.) at Bharat Forge Limited. The system consists of a frame structure designed to support the motors, sensors, and actuators controlled by a microprocessor. A load carrying structure compatible with the existing gantry is to be designed in order to upgrade the measuring accuracy of the beam and measure its length without any contact with the beam. The frame will incorporate an actuating mechanism to carry out the measurements. The components have higher compatibility with other automated systems because of the standard strut channels of Bosch Rexroth. The F.A.B. is suspended on the hook which is connected to the main gantry system which helps in the movement of the F.A.B. throughout the unit. The measurement of the beam is to be carried out when it is on the hook. To make this process possible, operator has to ensure that the sensors or any other element of the system makes no contact with the beam.*

The proposed system consists of a LASER based distance measuring unit and a pair of proximity sensors. These sensors are actuated towards the beam with the help of DC Motors meshed with suitable rack and pinion assembly. A complete analysis for the induced stresses and displacement has also been carried out. The proposed frame is designed for the strength and load bearing capacity well within safety limits. In order to validate the proposal, a prototype is prepared using similar components with a relatively less accuracy.

Key Words: **Automation, Linear Measurement, Bharat Forge Limited, Industry 4.0, SimScale.**

1. INTRODUCTION

With the continuous increase in automation and shifting of industries towards Industry 4.0, the consumers demand manufacturing with higher accuracy. The practice of visual inspection for measurement provides an accuracy up to 1 mm only, provided the worker is highly skilled and experienced. Still, this measurement involves many errors like parallax and human error. Moreover, the repeatability is not achieved. These inaccuracies affect the tag time. In order to eliminate these inaccuracies and thus increase the percent of the accepted components.

Sensors with measuring accuracy of 0.1 mm should be implemented in the process. Since these sensors work on the laws of reflection of light, they can measure small linear variations.

At Bharat Forge Limited, the available system involves measuring of the beam manually with the help of a meter tape. This provides an accuracy of 1 mm only. A Front Axle Beam plays a crucial role for supporting the steering mechanism, dashboard, and wheel alignment of an automobile vehicle. It has a tolerance limit of 0.5 mm only. Any variations more than that is a rejected component. In order to achieve minimum rejection of the manufactured component, the length should be set well in limits. Since the Axle Beams are forged components a slight variation in length is inevitable. So, a batch of perfect beams from the manufacturer's end can be possible if the oversized or undersized beams are eliminated there itself. Currently, at Bharat Forge Limited the beams are suspended on hook and have wet paint over them. The actual dimensions of the beam are confidential, hence for our simulation purpose and for programming the microcontroller we have considered the appropriate values as per our convenience.

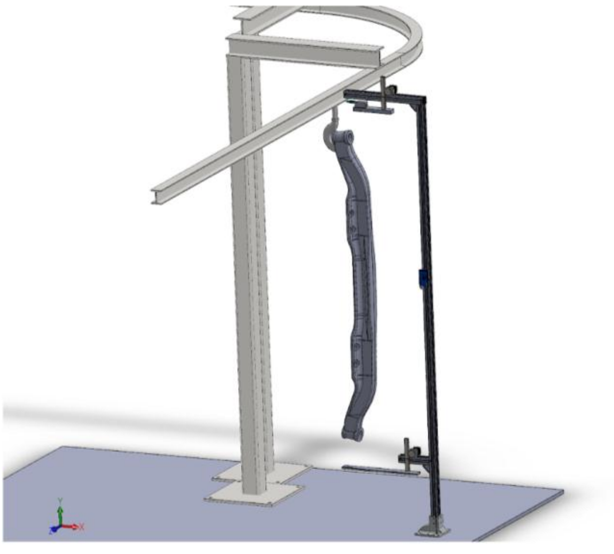

Figure 1: Proposed setup

2. DESIGN AND ANALYSIS OF THE FRAME STRUCTURE:

The desired frame has to be designed in a manner that it should not require any form of modification in the current setup. Moreover, the design should make use of minimum space while providing the structural strength to bear the load of the sensors and motors. Considering these constraints, we have selected Aluminum Strut Profile by Bosch Rexroth. For our required loads, the 40x40X10mm Square Profile has been selected. Later, the dimensions of the frame were calculated. The maximum allowable height and width the location are 3000 mm and 1000 mm respectively. The design of the frame has a height of 2400mm and width of 450 mm. Further, the 2D cross section of the selected strut channel is given below.

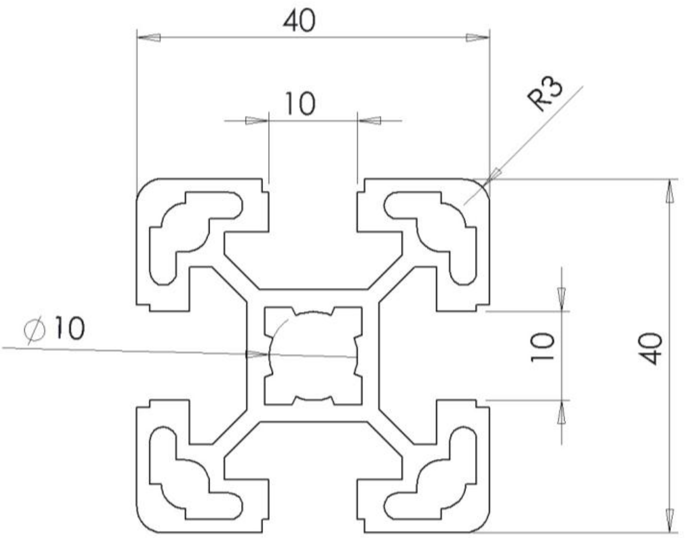

Figure 2: 2D Cross section of the strut

As seen in the figure, the strut has a channel width of 10mm which is suitable for accommodating various standard electronic components. One of the reason to select this particular strut is that, a standard strut provides high compatibility with the available automation system or for any modification in the future.

Figure 3: CAD Geometry of the strut with volume mesh

The strut geometry was constructed on Solidworks Software, and the meshing as well as stress and displacement analysis was carried out on a cloud based simulation application, SimScale. The analysis was performed considering the following constraints.

Material	6061-T6 Aluminum Alloy
Ultimate Tensile Strength	1.1E+8 Pa
Yield Strength	9.5E+7 Pa
Young's Modulus	6.9E+10 Pa
Mesh Size	0.05 mm
Structure type	Cantilever Beam
Load on the free end	30 N

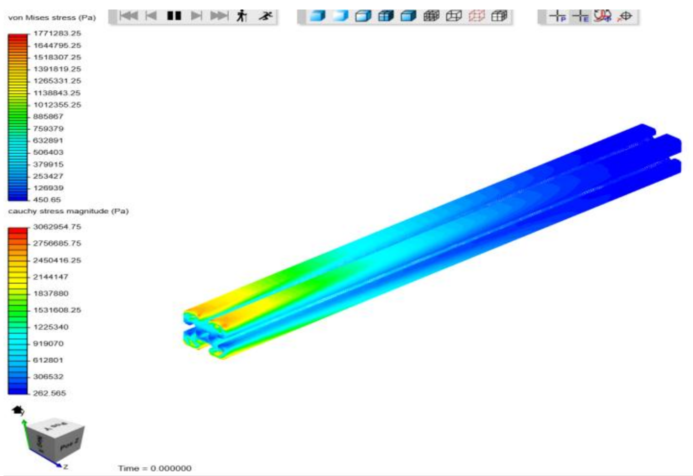

Figure 4: Result of the Von-Mises stress analysis of the strut

The result analysis gives us the value of maximum and the minimum stress and displacement. As per the analysis, the maximum stress induced is 1.77 MPa. The maximum tensile strength is well below the ultimate tensile strength. The design can thus be considered to be safe to implement.

3. DESIGN AND ANALYSIS OF RACK AND PINION MECHANISM:

A rack and pinion is a sort of straight actuator that involves a couple of apparatuses which convert rotational movement into direct movement. A round apparatus called "the pinion" draws in teeth on a direct "rigging" bar called "the rack"; rotational movement connected to the pinion makes the rack move with respect to the pinion, in this way interpreting the rotational movement of the pinion into straight movement. For each combine of the conjugate involute profile, there is an essential rack. This essential rack is the profile of the conjugate apparatus of limitless pitch range (i. e. a toothed straight edge). The parameters considered during designing the spur and rack are mentioned below.

Item	Symbol	Formula	Spur Gear	Rack
Module	m		2	2
Pressure Angle	α		20	20
Number of Teeth	z		20	28
Coefficient of Profile Shaft	x		0.6	
Height of Pitch Line	H			20
Working Pressure Angle	α_w			20
Centre Distance	a_x	zm/2 + H + xm	22.85	22.85
Pitch Diameter	D	zm	40	
Base Diameter	D_b	d cos α	35	

The material for the spur and rack are the same as of the strut. The spur and the rack were created using Solidworks and were analyzed using SimScale software.

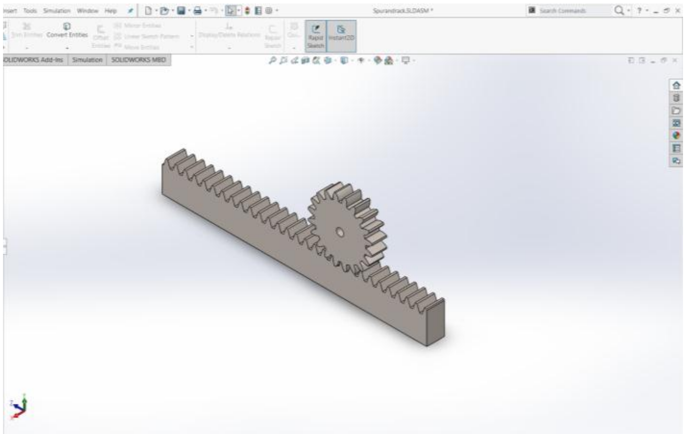

Figure 5: 3D Geometry of the spur and rack geometry

The mesh was constructed with a minimum elemental size of 0.05mm. Since the number of teeth in contact are two, during analysis, a force of 30N is considered on two teeth.

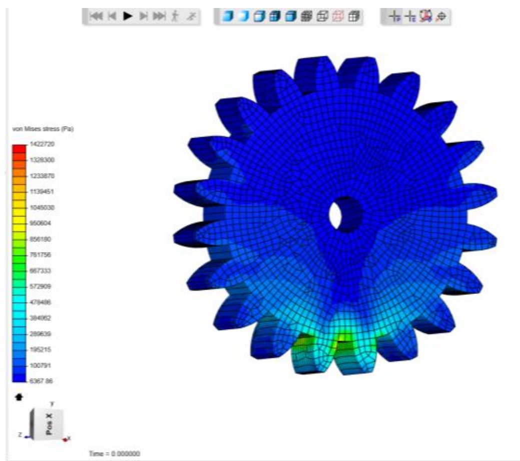

Figure 6: Result of the Von-Mises stress analysis of the spur

The maximum stress calculated after the analysis is 1.42 MPa. The maximum stress is quite lower than the Ultimate Tensile Strength. So the design is safe to implement.

4. DEVELOPMENT OF THE SENSOR CIRCUIT:

After the beam has been dipped in the paint, the proximity sensor and the distance sensor work in unison to measure the length. As the sensors that we have used are optical sensors, this helps us in achieving contactless measurement of the beam as the beam has been just dipped from the paint. The following flowchart explains the working of the program deployed in the Arduino MEGA.

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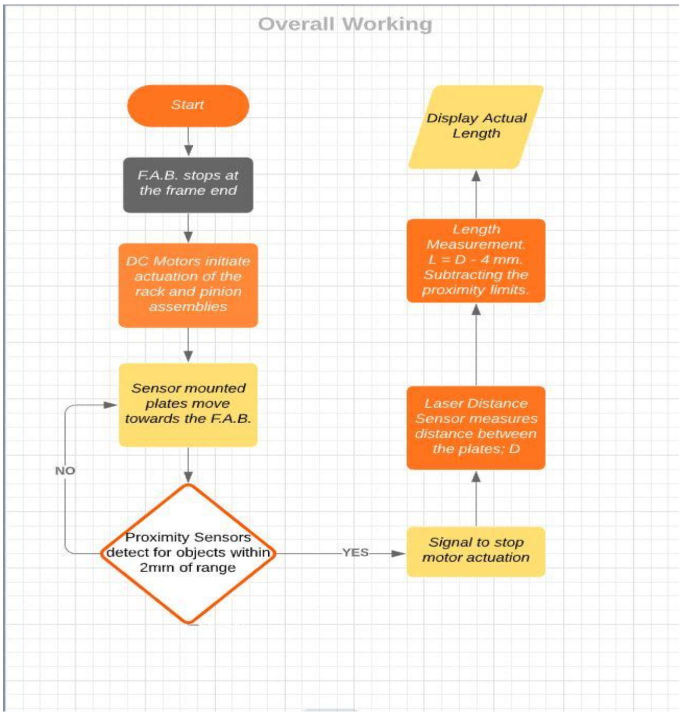

Figure 7: Flowchart for the overall working of the system

The entire circuit consists of two proximity sensors and one Laser Distance Sensor by Baumer Sensors. The distance sensor has an accuracy of 0.1mm and the proximity can detect an object within a range of 2mm. With reference to the Figure 1, we can get an idea of the total assembly. When the circuit is switched on, the Arduino board sends signal to both the motors and the motor starts to rotate at 100 rpm. The motor is coupled with spur gear of the spur and rack mechanism. The racks are attached to the plates with sensors flushed inside it. Movement of the racks causes the plates to move towards the F.A.B. As soon as the plates are 2mm apart from the F.A.B., the proximity sends an impulse to the microcontroller which then stops the rotation of the DC motors.

4.1 Implementing the concept of time of flight: When the motors stop, the laser distance sensor is activated and it shoots a laser vertically downward. The laser from the distance sensor strikes the lower plate and reflects back to the sensor instrument, which also has a receiver in it. The time required for the laser to travel back and forth is noted. Now, we have the time required for the light to travel, and the speed of light in air is 3 X 10^8 m/s. With these values, we can now calculate the distance between both plates. But, the actual length of the F.A.B. is calculated by subtracting 4 mm from the final length read by the distance sensor. This is the sensing range of both of the proximity sensors.

The code that has been developed, should be deployed in Arduino MEGA board. The list of the sensors to be used are mentioned as below.

	Name: Laser Distance Sensor Model: OADM 250I1101/S14C Manufacturer: Baumer
	Name: Proximity Sensor Model: CFDK 30P1600/S14 Manufacture: Baumer

Use a DC motor with a 12V input, 100rpm to interface with the Arduino board. The connection diagram of these instruments with below specified power supply is as follows.

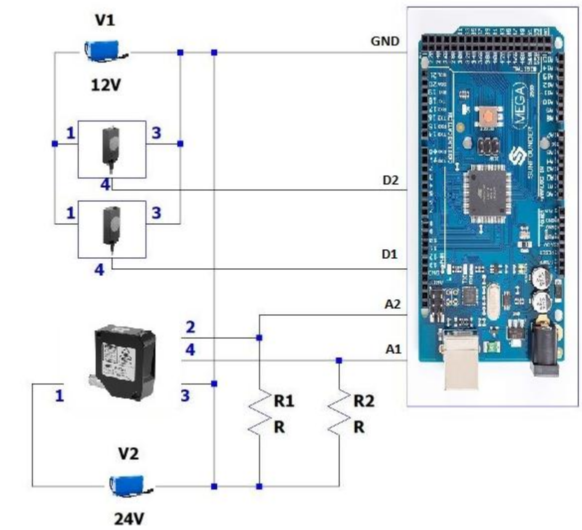

Figure 8: Connection diagram of the system's circuit

5. VALIDATION OF THE SYSTEM USING PROTOTYPE:

Since the above mentioned project consists of very specific purpose instruments and these instruments are expensive too. A physical prototype was prepared to validate the actual system. The prototype design mentioned below can also be used to carry out small scale measurements. The accuracy of these instruments is 0.5mm and the complete prototype can measure a maximum length of 30cm. All of the instruments of the prototype are similar to the instruments used for shop floor implementation. The code developed for this entire project can be used for shop floor implementation as well as the prototype with appropriate modification as per requirements. The length measurements are segregated into their respective groups according to their respective allowances in mm.

Use below mentioned circuit diagram as a reference for the circuit connection of the prototype.

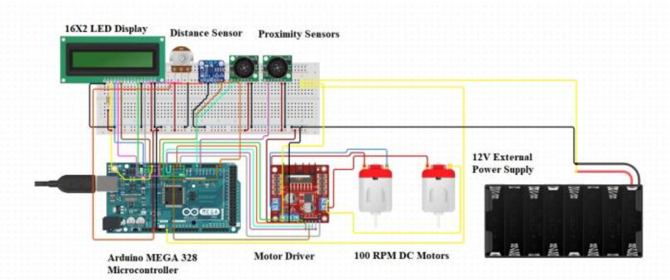

Figure 9: Connection diagram of the prototype circuit

For the prototype, the following components are used.

Sr. No.	Component	Model Name	Quantity
1.	Microcontroller	Arduino MEGA 2560	1
2.	Proximity Sensor	E18-D80NK	2
3.	Distance Sensor	VL53L0X	1
4.	Display	LCD 1602 Parallel Display with 10k ohm potentiometer	1
5.	Motor	12V 100rpm DC motor with L293D driver shield	2
6.	Power Supply	12V 1.5 Amp power adapter or an 8XAA pack of batteries	1

Table for Figure 9

6. CONCLUSION:

We have, thus, successfully developed and analyzed the proposed automated system. The proposed system can be implemented considering its merits over the existing measurement system. The safety of the workers and the payback period are within considerable limits. Mainly, an accuracy of 0.1mm is obtained. The system is purely based on the optical instruments which satisfies the objective of creating a clean environment. The primary objective of this project is to reduce the tag time, human risk, and increase the measuring accuracy. By implementing this system, the overall process comes one step closer to achieve the concept of Industry 4.0. The system makes use of Arduino Microcontroller which can be further interfaced to achieve IoT and get regular updates of the process.

7. SCOPE FOR FUTURE:

1. The code developed for the Arduino consists of multiple variables, combined into generalized equation. This feature allows the user to the setup for any required length, considering they have the suitable hardware.

2. The frame is made using standard strut profiles, and hence can be easily coupled with any existing or upcoming automation system.

3. With an Arduino microcontroller at its core, the entire system can be used for an IoT project and the supervisor can have access to the control and readings from different geographic location.

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