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A Machine-based Robotic System for Precision Grinding Wheel Saw Replacement: Mathematical and Non-linear Analysis Perspective

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Abstract:
Steel is general material which is used in many applications and the demand of steel is huge in the world market. As the demand is huge then the industry need to produce the steel component in mass quantity. The cutting operation is done with the grinding wheel saw known as saving operation which need to be replaced frequently as it warn out quickly. The replacement need time which creates impacts on the productivity of needle, to avoid such delay in replacement an automatic system will be needed. This paper presents grinding wheel saw replacement through an intelligent robotic system, powered by machine technology, designed to swiftly replace grinding wheel saws. This system consists of mechanical arm with 6 axis and DOF manipulator. For the analysis purpose of newly system design FEA is applied. For the detection purpose a digital cam is placed for the positioning of machine vision. To test the system thousands of actual results are measured and collected for the reliable working of newly proposed system.

Keywords: Saving operation, grinding wheel saw, Machine based robotic intelligent system, FEA.

1. Introduction

Recently, intelligent and smart technology in manufacturing has been highlighted to drive the steel sector, which has launched many projects to improve production quality and efficiency and at the same time reducing intensity of human labour [1-5]. Moreover, the steel industry experienced a surge in the integration and utilization of automated machinery due to the global support for Industry 4.0 development initiatives[6-9]. The process of sawing, cutting, and grinding for different materials components, automated technology which is advanced significantly. It has been reported that car wheel polishing [10, 11], intelligent grinding wheel monitoring [12], and automated casting debarring [13]can be possible with Machine based robotic intelligent system (MRIS). The need for higher-quality steel goods such as different steel section has increased exports. A steel product that has been cut with a grinding wheel saw has a smooth cut without burrs, and with a very good manufacturing quality. During the normal operation of the machine, the sawing speed is consistently maintained at a specific value to ensure uninterrupted progress in the sawing task. Because steel is being sawed at a great speed, the generated friction quickly wears out the saw. For the sawing, to achieve a steady circumferential speed, the spindle's rotating speed must be continually increased. As the process continued the saw diameter decreased gradually, it reduces the circumferential speed which then creates impact on smooth operation. Which means operator needs to change the saw frequently [14].

In the steel industry the use of automated machinery has not completely replaced the saw in the process of cutting steel round bars.Typically, it takes more than Two hours to conduct a manual procedure to replace a saw. In addition, the manual replacement of saw comes with a number of drawbacks. With the advancement of robotic system, the robot system has emerged as a key piece of machinery for resolving issues with sawing, cutting, and grinding in the steel sector. The robot system offers considerable practical application versatility. By using robotic system, manufacturing quality and efficiency are unquestionably increased over manual operation. The robot system is increasingly and widely used for spraying, polishing, grinding, cutting, and other activities on steel and casting [15–17]. As a result, the steel industry now urgently needs to deploy robotic system rather than manual operation to ensure the effective replacement of saw. The foundation of encouraging the quick advancement of sawing technology in the steel sector is the advancement of significant innovations for the robotic system equipment.

2. Experimentation& Analysis

2.1 Proposed system machine based robotic intelligent system

Fig. 1. Sawing Machine

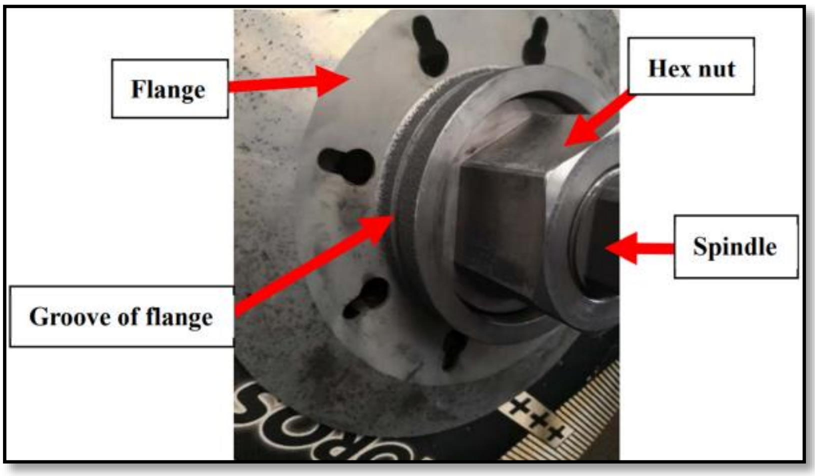


Fig. 2.Spindle with flange and nut

The proposed sawing machine is as shown in figure no 1. As indicated in Figure 2, with the flange and nut the saw is positioned on the spindle. The newly developed equipment is responsible for addressing the challenges associated with disassembling and reassembling flanges and hex nuts, as well as facilitating the transfer of the new and old saws, enabling the seamless replacement of the saw through automated means.The grinding wheel saw replacement through an intelligent robotic system, powered by machine technologyis created and described in this study in order to successfully fulfil the task of replacing the saw. The MRIS of saw in Figure 3 is mostly made up of 2 components.

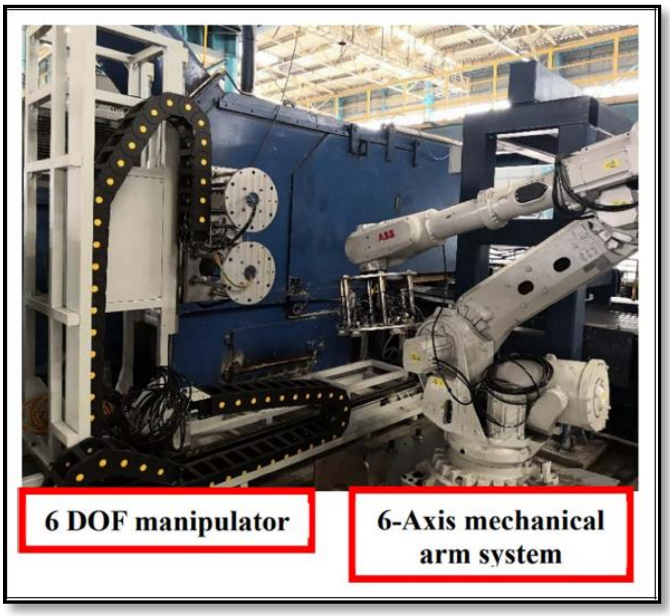


Fig.3.Machine based robotic intelligent system (MRIS)

The proposed system consists of 2 different parts as 6 DOF manipulator and mechanical system with 6 axis arm. The manipulator includes the tightening and un-tightening module for the flange and nut whereas mechanical system consist of 6 axis arm to transport the new and old saw with the help of vacuum sucking equipment, also a digi-cam is setup for the location perfection.The entire control system has been configured to accommodate the machine vision locating system connected to the digi-cam. Figure 4 shows the functional blocks of the MRIS.

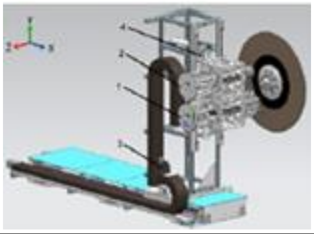
	Movement	Items of Module	Components	Functions
6 DOF manipulator 	Horizontal motions (X-axis Servo Motor)	Unscrewed & tighten module (UTM)	1. Z axis linear pneumatic cylinder 2. Position Sensor	Pneumatic wrench (unscrew/tighten nut)
	Vertical motions (Y-axis Servo Motor)	Dismantled & assembly module	1. Z axis linear pneumatic cylinder 2. Position Sensor	Servo motor (Screw out/in the nut)
				6 pneumatic latch cylinder with sensor
6 axis mechanical arm system 	Transportation of GWS	ABB 6 axis robot arm		Move the VSAM
			6 Vacuum sucker	Adsorb/release saws
		Vacuum sucker adsorption modul (VSAM)	Digital camera	Detect the image for positioning system

Fig.4. Functional blocks of the MRIS

The operating procedure of proposed MRIS is mentioned below;

- **Step 1:** Digi-cam detected the nut centre position which is situated on spindle. This result are performed by machine based robotic intelligent system and then forwarded to the control panel system.
- **Step 2:**The digital camera detects the position, following which the 6-degrees-of-freedom manipulator proceeds to nut unscrewing &remove flange from system.
- **Step 3:**Mechanical structure arm pick the old saw and put the same in to storage place and then pick new saw and placed on the spindle with vacuum operated system
- **Step 4:** The 6 DOF manipulator tight the screw after placing the flange on the spindle as the position is again detected by digi-cam.

Figure 5 shows the 6 DOF manipulator, the size of manipulator is 3760mm x 2485mm x 1130mm.

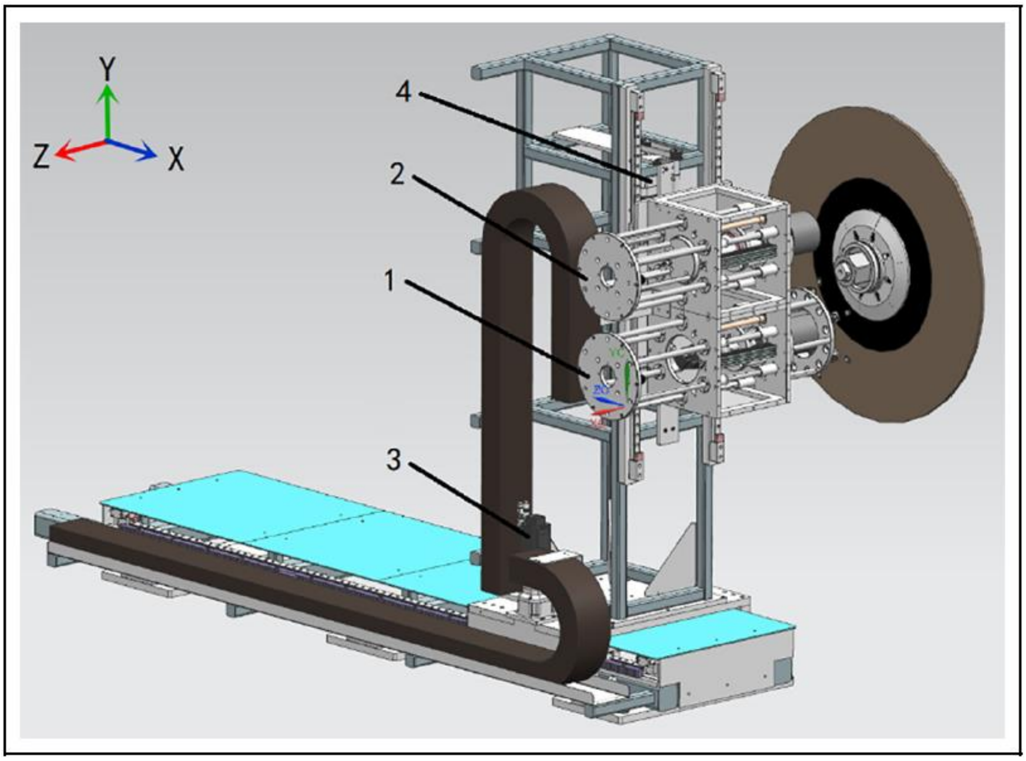


Fig.5. The 6 DOF manipulator

2.2 Disassembling and assembling of nut

The nut is disassembling and assembling is done with the help of sleeve which is connected to the pneumatic wrench. To establish engagement and disengagement, the sleeve must be positioned so that it is parallel to the spindle's centre axis. Figure 6 shows the schematic view of disassembling and assembling module. Module contains the translational and rotational frame, sleeve, pneumatic wrench, elastic coupling. To develop rotational frame, sleeve is connected with pneumatic wrench output shaft through coupling.

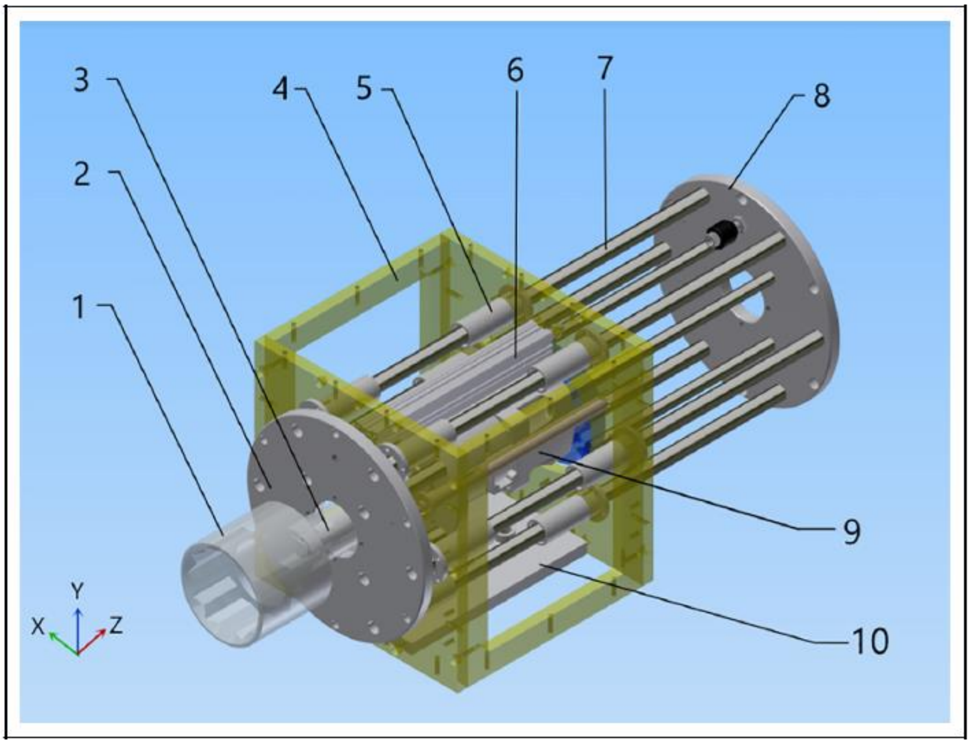


Fig.6. Schematic view of the Disassembling and assembling unit
(1. Sleeve, 2. Front flange, 3. Coupling, 4. Bearing frame, 5. Bearing, 6. Pneumatic cylinder, 7. Connected rod, 8. Rear flange, 9. Pneumatic wrench, 10. Bottom plate)

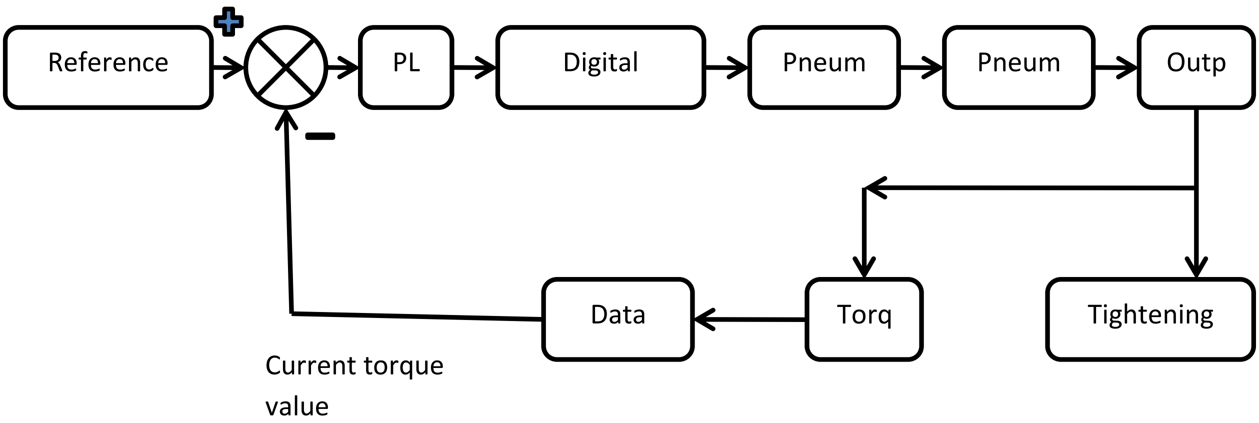


Fig.7 Control system (regulated torque feedback)

2.3 Mechanical system arm with 6 axes

The work of replacing the old and new saw is carried out in the sequel after the previously mentioned 6 DOF manipulator has finished disassembling the flange and nut. The planned mechanical system arm with 6 axes, which incorporates the vacuum sucking for dismantling, assembling, and moving the saw, is described in the research. This is in accordance with the available workspace in the industrial site as well as the size and weight of the saw. Figure 8 shows the schematic view of mechanical system arm with 6 axes.

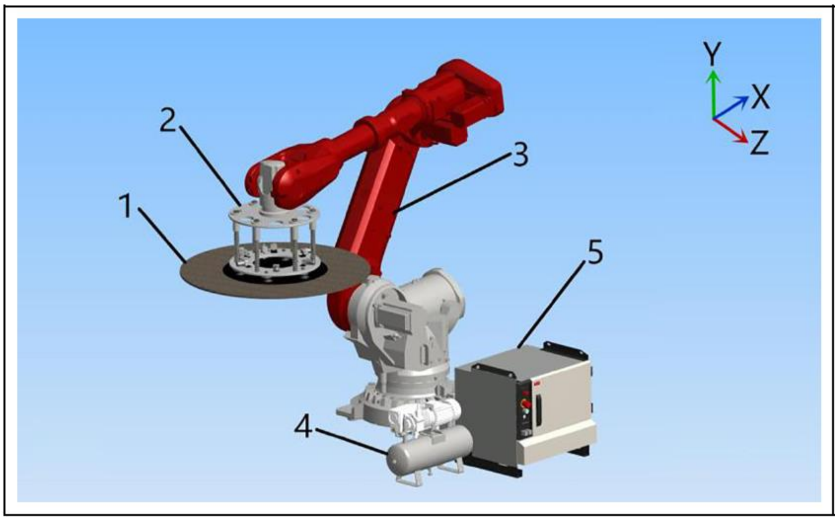


Fig.8.Schematic view of mechanical system arm with 6 axes.
(1. Saw, 2. vacuum sucking module, 3. Robot arm, 4. Compressor, 5. Control box)

2.4 Vacuum sucking module (VSM)

The vacuum sucking module (VSM), which is put at the termination point of the 6-axis robotic system, is designed to enable the disassembly, installation, and movement of the saw. Figure 9 shows the schematic view of VSM.

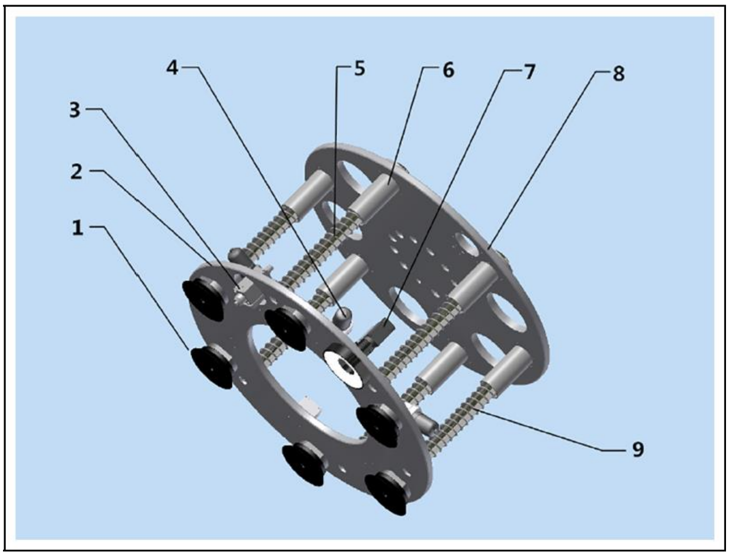


Fig.9. Schematic view of vacuum sucking module (VSM).
(1. Vacuum suckers, 2. Front flange, 3. Contact sensor, 4. Vacuum generator, 5. Buffer spring, 6. Bearing, 7. Digi-cam, 8. Rear flange, 9. Connected rod)

3. Finite element analysis (FEA)

To test the mechanical structure for the displacement, strain, and stress value, the finite element is a regular method [18]. ANSYS software is used for the complete analysis of the newly proposed system [19,20]. Aluminum is considerd as the structural material. The tetrahedran meshing process is done on VSM 3D model with saw (which is generated by CATIA software) with the help of ANSYS software. Figure 10 shows meshing with 65981 nodes and 94572 elements.

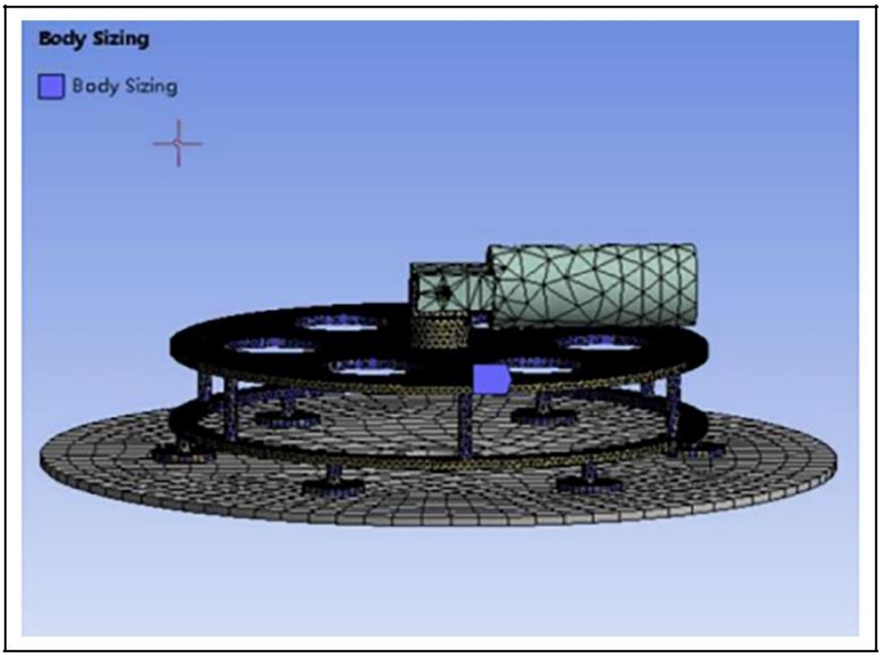


Fig.10.Meshing of VSM

Figure 11 shows the gravitational force operating on the VSM is primarily taken into account in FEM since the saw moves slowly throughout the transport process. Figures 12 to 14 show, respectively, how displacement patterns & equivalent stresses for Variable Speed Motor (VSM) using three distinct diameter values400, 800, and 1000mm were calculated using the FEM programme.

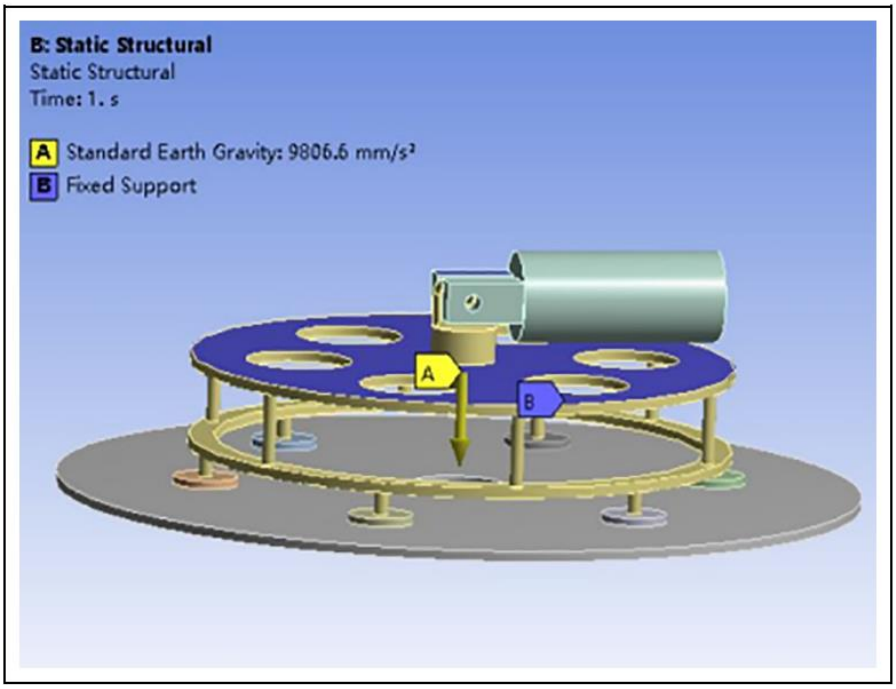


Fig.11.Gravity action on VSM

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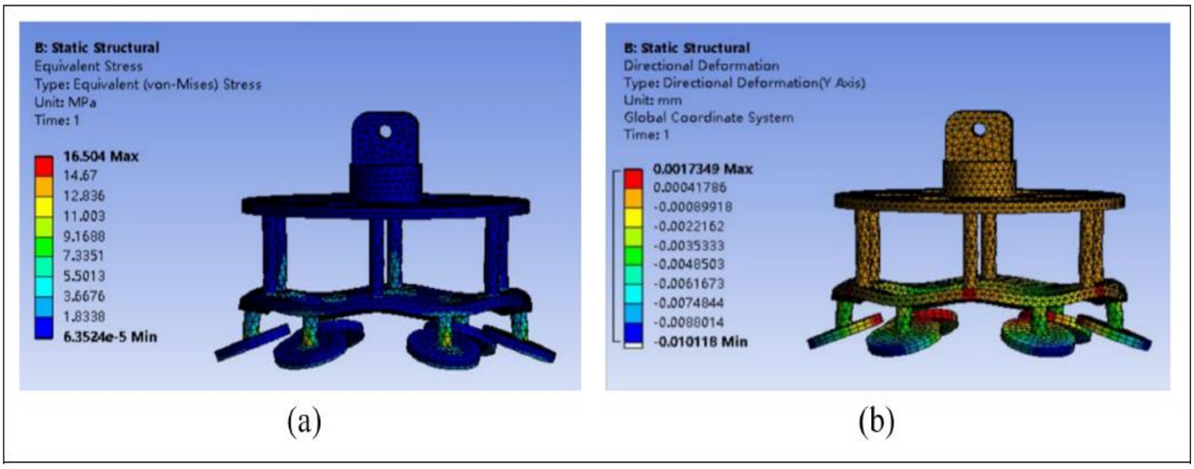

Fig.12. (a) Von Mises stress distribution and (b) Displacement distribution with 400 mm (diameter)

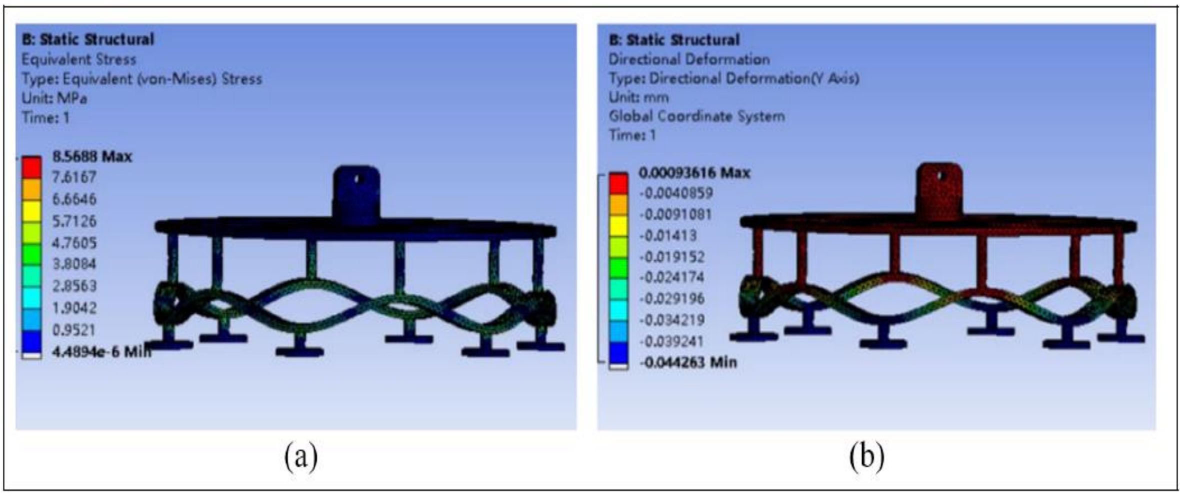

Fig.13.Von Mises stress distribution and (b) Displacement distribution with 800 mm (diameter)

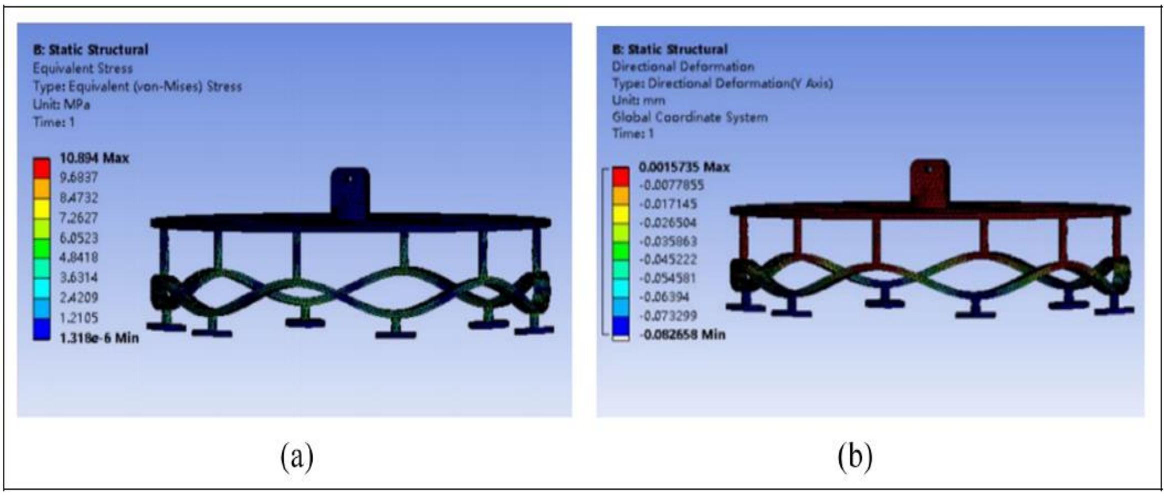

Fig.14.Von Mises stress distribution and (b) Displacement distribution with 1000 mm (diameter).

3.1 VSM Deviated displacements (Analysis and discussion)

The ANSYS programme creates the mesh for the prototype vacuum sucking 3D model. There are 40552 elements and 57323 node numbers as a consequence of the meshing. A silicon rubber substance is used as the structure's material. Figures 15 and 16, respectively, show how the finite element programme calculated the vacuum sucking's displacement and Von Mises stress distributions along the horizontal and vertical axes.

1. Its flexibility is achieved through the use of rubber material, ensuring that the Hoover sucker maintains sufficient suction force. Due to the influence of the outside force, it results in the deformation of the vacuum sucking module.
2. It is determined that the location of the saw's central axis is shifted during the transition from a horizontal to a vertical orientation, when the VSM absorbs the saw's operation load.
3. According to finite element simulation results, the vacuum sucker exhibits a maximum vertical displacement of 13.12 mm and a maximum horizontal displacement of 4.15 mm.

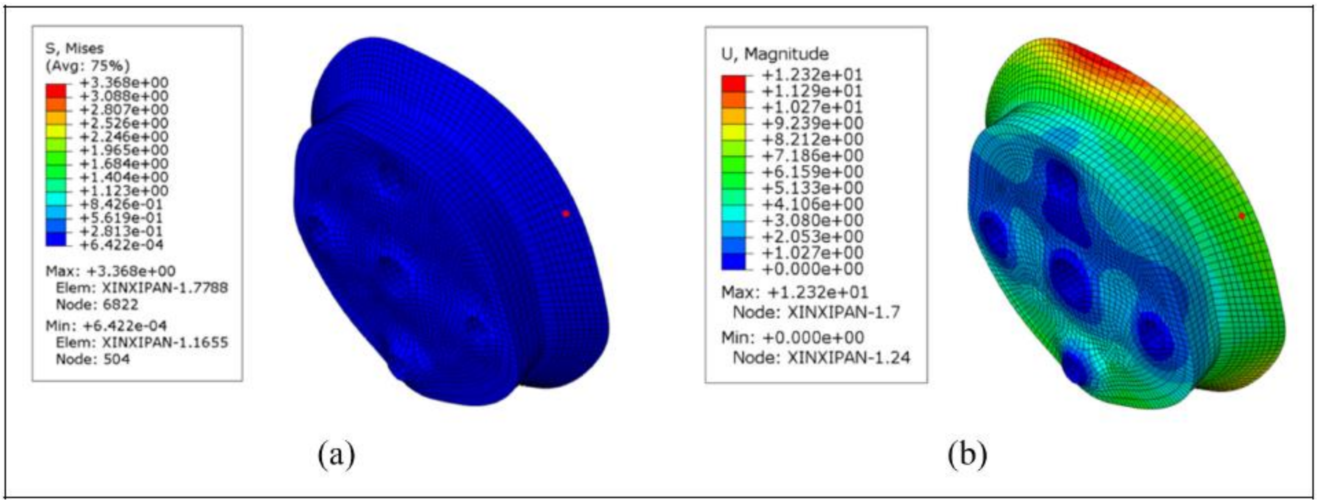

Fig.15. (a) Von Mises stress distribution (b) Displacement distribution in the vertical direction.

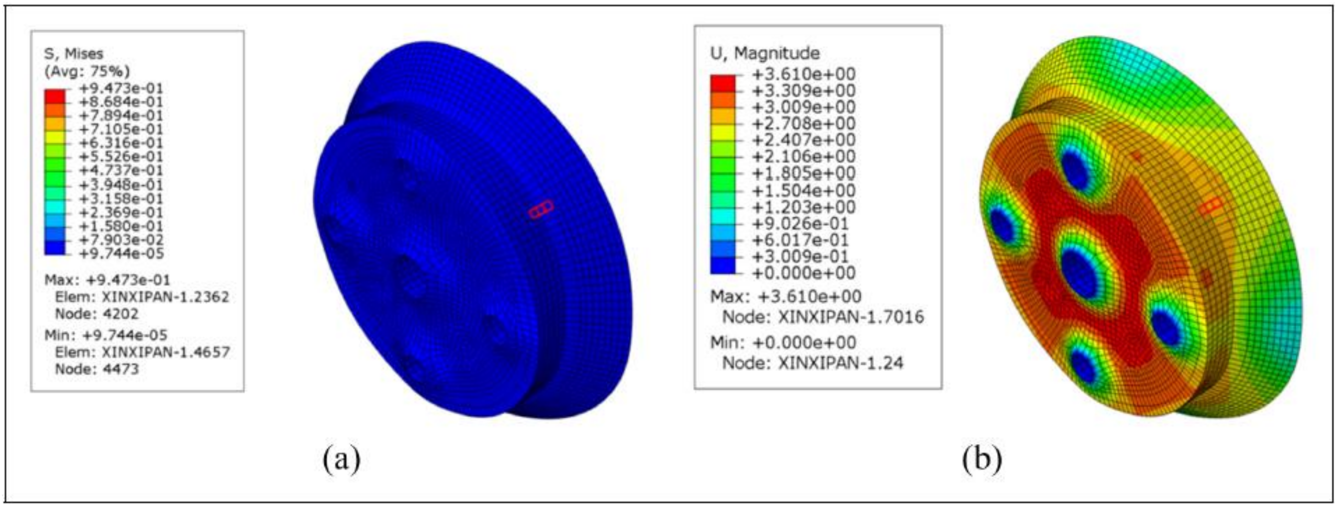

Fig.16.(a) Von Mises stress distribution (b) Displacement distribution in the vertical direction

4. Machine-vision location mechanism

The machine vision positioning system is utilized by the steel circular bar sawing apparatus to detect images through camera installed at the end of the VSAM. Its purpose is to determine where hex nut's axis is located, within the workspace. Qiu. S et al. [21] have described the machine-vision placement mechanism's precise configuration for the GWSs' intelligent robotic substitution mechanism.

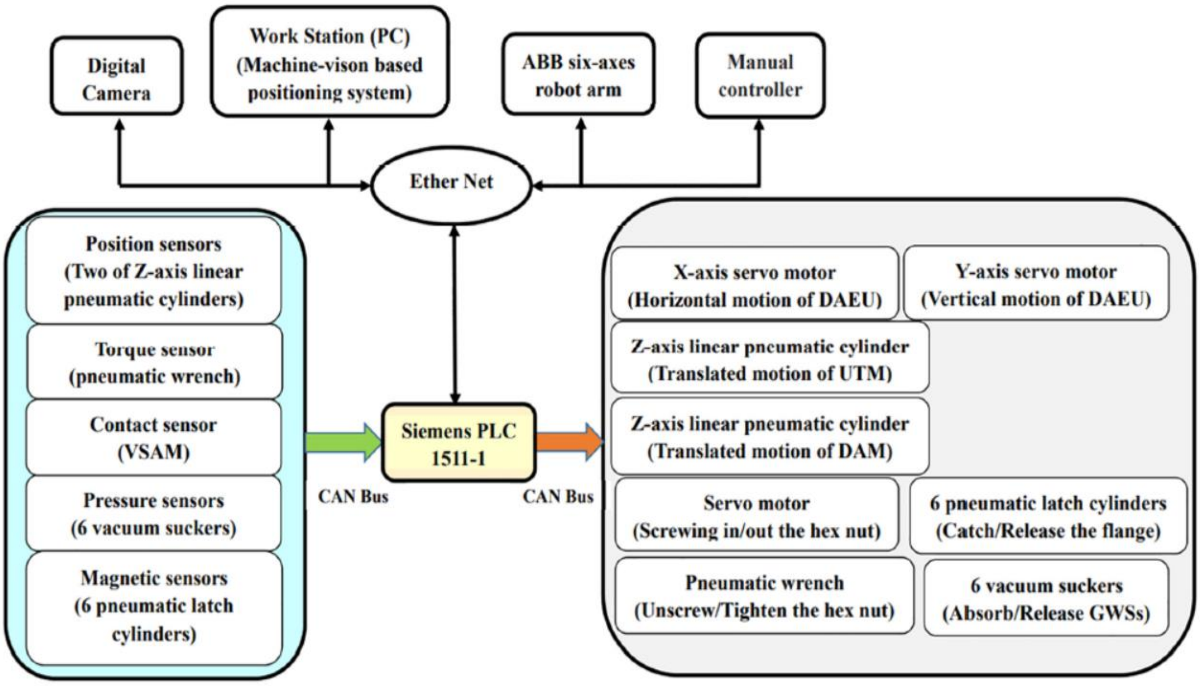

Fig.17.The MRIS's hardware system interconnection architecture.

Flow Diagram for Controlling Saw Wear, in Steel Round Bar Sawing Machine:

The control system of steel circular bar sawing apparatuskeeps track of the operating saw's level of wear. When diameter of the saw decreases from 1200 to 700mm due to wear from sawing the control system generates a signal indicating that it's time to replace the saw. The operations involved in this process are outlined in the following control flow chart, for MRIS.

- **Step I** :Once the signal received for replacement the Programmable Logic Controller (PLC) instructs the six axis arm system to start moving. At the time the digital camera attached to the arm begins capturing images for the machine vision positioning system.
- **Step II :**Control system calculates and provides the positions of both the axis of hex nut & old saw.
- **Step III :** The Universal Tool Manipulator (UTM) is positioned for operation. A pneumatic wrench unscrews the hex nut.
- **Step IV :**Disassembly and Maintenance mechanism is adjusted to position of dismantling. It removes flange and hex nut from the spindle, after which it moves backward to prepare for subsequent assembly tasks.
- **Step V :** After confirming the successful dismantling of flange& nut, the mechanical arm system (6-axis) equipped with the VSM removes the old saw and transports it to the designated

storage area for disposed grinding wheel saws. Next, the new grinding wheel saw is acquired and conveyed for insertion onto the spindle.

- **Step 6 :** Once the PLC verifies the completion of saw replacement, the Disassembly and Maintenance (DAM) mechanism carries the flange and hex nut, relocating them to workstation of assembly.
- **Step 7 :**Disassembly and Maintenance positions itself to finalize the mounting of nut& flange onto spindle, and subsequently returns to its original location within DAEU.
- **Step 8 :** UTM is directed to operational location, where a driven pneumatic wrench is employed to securely fasten the hex nut. Subsequently, the UTM reverts to its original position within the DAEU.
- **Step 9 :** After completing the replacement task, the MRIS reset and prepared for the next task, starting again from Step I.

5. Actual test results and discussions:

To assess the MRIS's performance, an exhaustive and real-world examination of the saw replacement task was carried out. 300 test results were collected from the PLC , and without exception, they all demonstrated flawless execution of the replacement tasks. The central aspect of the 300 test results centered on the time needed to complete the saw replacement task with the MRIS. The computed average total operation duration was 421.0 seconds. In stark contrast, manual replacement methods typically take over 30 minutes to complete the same task. Thus, the MRIS exhibits remarkable efficiency in its operations.For a more in-depth assessment of the system's performance, the average total operation time was segmented into 4 distinct stages. The percentages of time allocated to different stages are as follows: Disassembling and reassembling the flange and hex nut (59%), removing and installing the saws (34%), and the remaining time dedicated to other tasks (4% and 3% respectively). This analysis indicates that the most time-consuming aspect of the replacement task lies in the process of disassembling the flange and hex nut from the spindle.

6. Conclusions

Steel bar sawing machine in the industry has been equipped with the MRIS specifically designed for the saw used in the process. The following concluding remarks summarize the system's features and accomplishments:

1. The developed system comprises three primary components: a machine-vision positioning system, a 6-degrees-of-freedom and 6 manipulator, a 6-axis mechanical arm system. These components work in synergy to ensure efficient and precise replacement of saws.
2. The 6-DOF manipulator incorporates two essential modules: the module responsible to unscrew and tight, known as UTM, & module for dismantling & assembly, referred to as DAM. This manipulator is capable of disassembling and assembling nut & flange on spindle, facilitating seamless replacement.
3. 6-axes mechanical arm system features a 6-axes arm of robot equipped through a module of vacuum suction. Efficiently of module of vacuum suction handles tasks such as absorbing and transporting the saws, enhancing the overall functionality of the system.

   Detailed descriptions of the flow Chart for Controlling Saw Wear and hardware system architecture are provided, ensuring a comprehensive understanding of the system's structure and operation.

4. Realistic testing results have been gathered and analyzed to verify the system's reliability and confirm its exceptional working efficiency. The testing results serve as empirical evidence supporting the system's effectiveness in carrying out saw replacement tasks.

In conclusion, the MRIS for steel circular bar sawing apparatus in industry demonstrates a robust and intelligent solution for saw replacement. Its integration of system positioning through machine-vision, 6 Degree of Freedom manipulator & 6-axes mechanical arm system, along with its well-documented hardware architecture and control flow, establishes its reliability and operational efficiency.

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