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Mechanical Design for the Six-degree-of-freedom Welding Robot Using Direct Motors

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Abstract— *With the continuous development of industrial automation, the demand for industrial robots in the manufacturing field is constantly increasing. Using commercially available direct drive motors to design and build the six-degree-of-freedom robot that performs tasks is essential. The research object of this paper is the mechanical design of the industrial welding robot with six degrees of freedom using mainly direct drive motors with calculating the durability for the links in the robot and the maximum displacement of the welding gun head.*

Keywords— *Industrial robot, six-degree-of-freedom welding robot, direct drive motor, displacement, welding gun head.*

I. INTRODUCTION

An industrial robot is an electromechanical product in modern industry, usually a robot with 6 degrees of freedom. The more degrees of freedom, the higher the robot's flexibility, but the programming will be more difficult, and the cost will be higher [1-3]. These robots are mostly used in repetitive jobs, typically the welding processes. In Vietnam, high-precision welding robots are mainly imported from the Japanese market, but their prices are quite high [4]. For small and medium-sized enterprises that can hardly invest in the economic direction. The robot market with a lower price in China will meet the economic problem for these businesses. Still, due to the security of the technology, most warranty and repair issues require the involvement of their specialists, leading to increased costs and production disruptions when these robots crash. To overcome this, developing countries like Vietnam tend to research and develop domestic welding robots by themselves, with the pre-established principle that the rest is to form a robot mechanical structure by these principles and ensure the required accuracy when the robot works [5]. The most difficult problem for research groups or production facilities is to choose the source of the drive for the joints of the robot; the structure of the robot's links ensures assembly with the tolerances of the links according to the specifications request. The source of the drive at the joints of the robot is mainly composed of motors for rotary joints and linear motors or hydraulic cylinders for translation joints. Most of the welding robot structures have rotary joints, and these joints can completely use motors in combination with belt drives, gears, etc. to reduce speed and improve moment on demand.

Therefore, choosing the types of motors, reducers, designing links for compact robot structure, easy assembly, and ensuring accuracy in the working process are the important keys to improving manufacturing robots' level, even advancing to improve competitiveness.

II. KINEMATIC DIAGRAM & WORKING ENVELOPE OF ROBOT

Industrial robots are usually made up of a fixed base and moving parts connected by movable joints. This diversity of the joints allows the robot to move in multiple directions and with high precision. This accuracy is highly dependent on the driving sources for the robot. In this study, the welding robot is designed with a drive source using 6 direct-drive motors with an integral reducer. The play in the reducer using the harmonic type has no or very little, making the robot's looping process very accurate, about ± 0.5mm for the position of the torch tip.

Figure 1 is the kinematic diagram of the 6-degree-of-freedom welding robot using a direct motor.

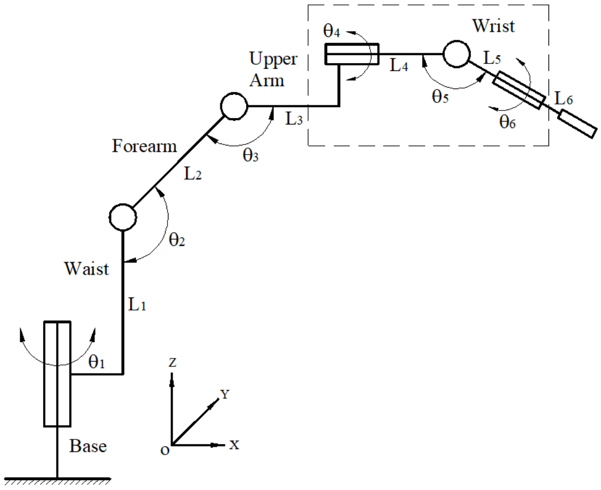

Fig. 1. Diagram of the 6-degree-of-freedom welding robot.

The robot has a maximum reach of 700mm, with the rotation limit of the joints: θ_1 ($-90^o \rightarrow 90^o$), θ_2 ($-60^o \rightarrow 90^o$), θ_3 ($-75^o \rightarrow 75^o$), θ_4 ($-90^o \rightarrow 90^o$), θ_5 ($-90^o \rightarrow 90^o$), θ_6 ($-90^o \rightarrow 90^o$). The large angular velocity of the moveable joints is the same and has a value of 360^o/s, with the size of the wrist stitches smaller than the arm stitches, which will help the robot be more flexible in the welding process.

III. MOTORS AT THE ROBOT'S JOINTS

Joints 1 to 4 of the robot use AC Servo direct-drive motors of type FHA-25C (see Figure 2), MSMD022G1A-AC servo motor (see Figure 3) combined with CSF-20-50-2UH harmonic reducer (see Figure 4) for slewing joint 5, and MSMD022G1A-AC servo motor combined with CSF-17-50-2UH harmonic reducer (see Figure 5) for rotary joint 6.

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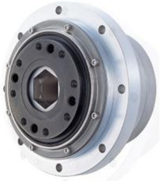


Fig. 2. The FHA-25C direct motor

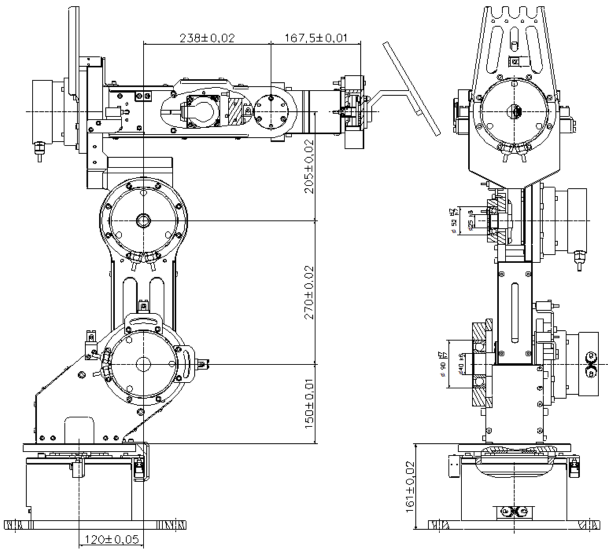
Fig. 3. The MSMD022G1A-AC servo motor

Fig. 4. The CSF-20-50-2UH harmonic reducer

Fig. 5. The CSF-17-50-2UH harmonic reducer

IV. THE 2D & 3D DRAWINGS AND MASS OF THE LINKS

The 2D & 3D structure of the welding robot with six-degrees-of-freedom (see Figure 6) is a combination of the kinematic diagram of the welding robot (see Figure 1), the driving motors at the joints (see Figure 2 - Figure 5), applying Autodesk Inventor 2015 software and design principles.



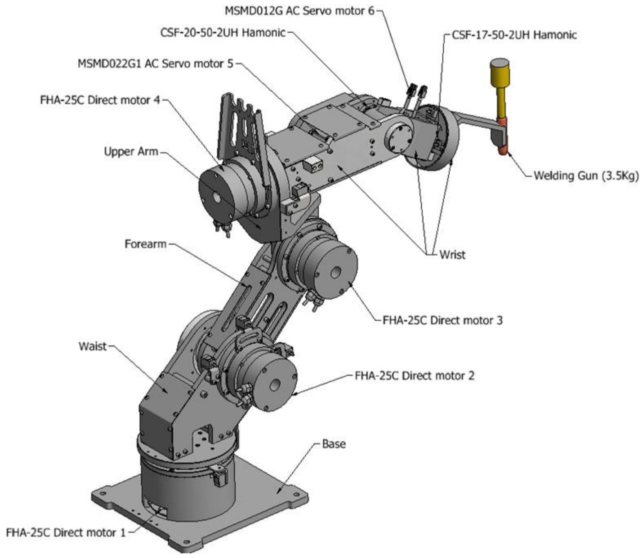


Fig. 6. The six-degrees-of-freedom welding robot's 2D & 3D drawings

The welding gun weighs 3.5 kg. The mass of the links, including the mass of the motors, respectively: base is 25.5 kg, link 1 is 18.5 kg, link 2 is 12 kg, link 3 is 10 kg, link 4 is 7.5 kg, link 5 is 3 kg, link 6 (including welding gun) is 4.5 kg.

V. STRENGTH TEST FOR LINKS, TORQUE OF MOTORS AND MAXIMUM DISPLACEMENT AT THE TIP OF THE WELDING GUN

The maximum rotational speed at the joints is 360 (^{o}/s), corresponding to 6.28 (rad/s), if the time to accelerate to speed limit from zero is 0.01(s) for 3 joints 4, 5, 6 (Wrist), the angular acceleration of the joints will be 628 (rad/s^2); if the time to accelerate to speed limit from zero is 0.2 (s) for 3 joints 1, 2, 3 (Waist, Forearm, Upper Arm), then the angular acceleration of these joints will be 314 (rad/s^2).

Consider the position of the robot where the motors will bear the heaviest loads. That is the position the robot reaches the farthest shown in Figure 7.

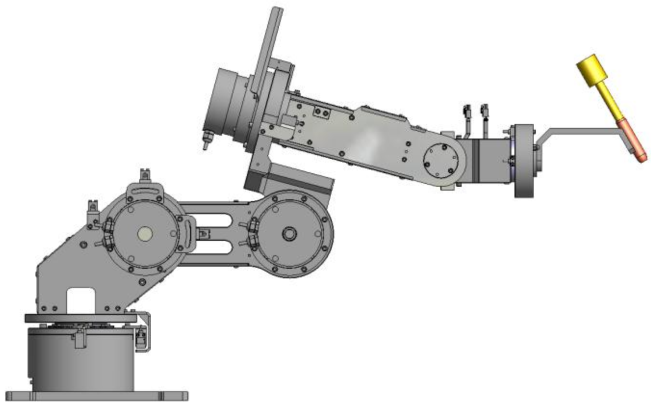


Fig. 7. Calculation position for the six-degrees-of-freedom welding robot

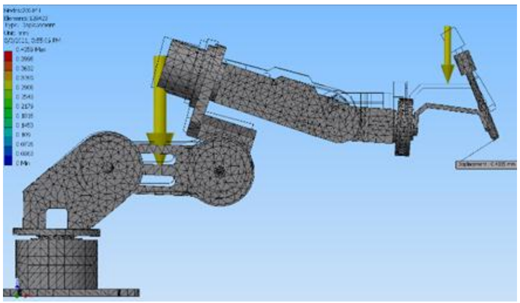
Use Autodesk Inventor 2015 software to test moment for motors.

TABLE I. Moment for motors.

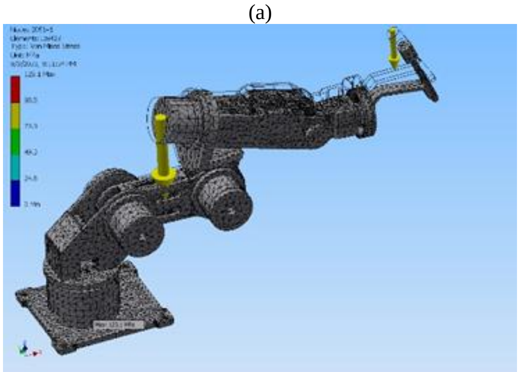
Link	Mass (kg)	Moment of inertia (kg×m^2)	Impeding torque/Anti-torque (N×m)	Allowable torque of motors (N×m)
welding gun + 6	4.5	0.013	4	16
5 + 6	7.5	0.095	29	32
4 + 5 + 6	15	0.055	17	150
3 + 4 + 5 + 6	25	1.033	64	150
2 + 3 + 4 + 5 + 6	37	1.612	101	150
1 + 2 + 3 + 4 + 5 + 6	55.5	3.213	140	150

From Table I shows that the torque of the selected motors is in accordance with the requirements.

The material of the robot's body is aluminum. Test results for the maximum displacement at the tip of the welding gun 0.44 (mm), the maximum stress is 123 (MPa) < the allowable stress is 206 (MPa) shown in Figure 8.



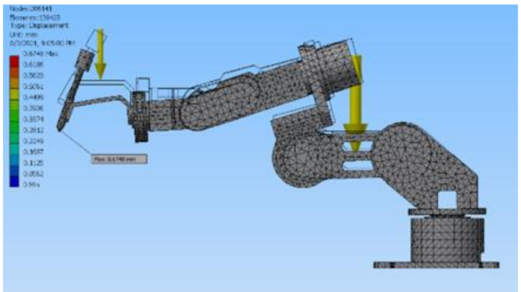
(a)



(b)

Fig. 8. Maximum displacement (a) and stress (b) of the six-degrees-of-freedom welding robot (The material of the robot's body is aluminum).

The material of the robot's body is steel. Test results for the maximum displacement at the tip of the welding gun 0.67 (mm), the maximum stress is 52 (MPa) < the allowable stress is 274 (MPa) shown in Figure 9.



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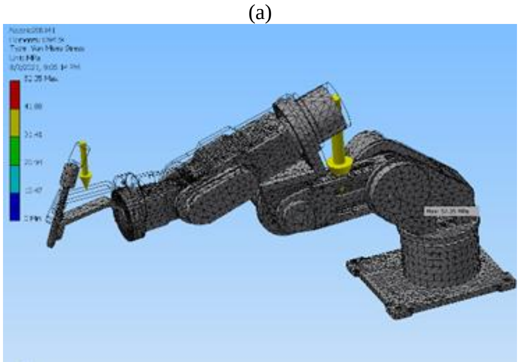

(b)

Fig. 9. Maximum displacement (a) and stress (b) of the six-degrees-of-freedom welding robot (The material of the robot's body is steel).

VI. CONCLUSION

This paper mainly talks about the mechanical design method for the 6-degree-of-freedom welding robot using the motor directly from the kinematic diagram of the robot. This study uses software to check the torque of the motors, the maximum stress on the structure and the maximum displacement at the welding gun head of the robot. With this result will determine the static error of the torch tip during the robot moving to the welding point.

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