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STUDY OF MATERIAL CHARACTERISTICS FOR EFFICIENT DESIGN OF SPRAY PAINTING ROBOT

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Abstract - *This paper is proposed to study material characteristics and material selection for industrial robots typically used for spray painting application. In this paper we studied material properties required for the design of a spray-painting robot, so that it can work efficiently for a long time. Initially this paper introduced spray painting robots and tried to describe why robots are required in spray painting applications. Then why material selection is required in spray painting robots and what are the basic properties of material required for the same. Then based on the required properties of material, we try to define some materials suitable for spray painting robots. This paper includes merits and demerits of all materials that we listed out for spray painting robot application. And lastly, we try to conclude the best suitable material for spray painting robots. For reference of spray-painting robot structure and design parameters we used data from reference [2].*

Key Words: **Industrial Robots, Spray Painting Robots, Material Selection, Aluminium Alloy, Structural Steel, Material Properties, Robot Base, Robot Arm**

1. INTRODUCTION

With the rapid development in science and technology, the conventional means of some industrial process like welding, painting, material handling etc are becoming advanced with industrial robots. Industrial robots are mechanical device which, to certain degree replicate human motions. They are used to whenever there is need to reduce danger to human, or continuous operation is required. The use of industrial robot has not only revolutionized the process of plant but it also speeds up the process and increases accuracy too. As a product of the combination of mechanical industry and information industry, industrial robots have two major advantages compared with traditional machines in terms of almost fully automatic productive process and high adaptability to production equipment [1]. There are various kinds of industrial robots, among which spray-painting robots are the typical representatives. In all professions and trades, especially in manufacturing industry, spraying paint on the surface of products is an indispensable process. However, the paint is extremely harmful to human body after atomization, the spraying room is generally airtight and ventilation conditions cannot be fundamentally improved at the same time, so the working environment of spray painters is relatively poor. In this case, the use of spray-painting robots can not only improve the working environment, but ensure the spray quality of products as well. [2]

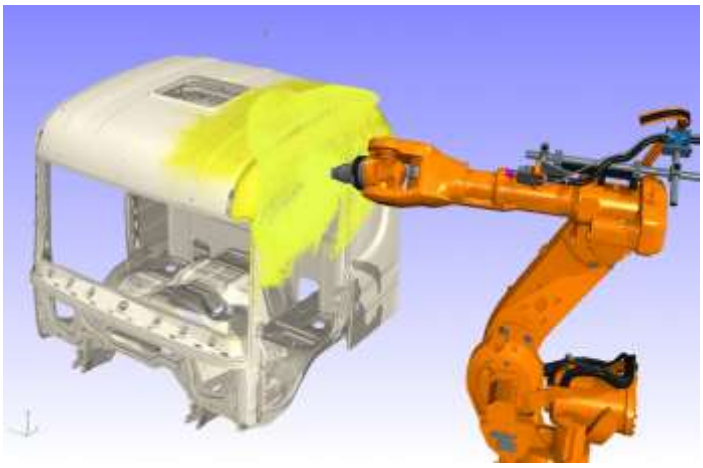

Fig -1: Spray painting robot used in industry

1.1 Advantages

- High consistency
- Better productivity
- Increased labours safety
- Less power consumption
- Minimizes the use of paint

1.2 Disadvantages

- Initial cost is little high
- Complex breakdown may stop production for long time
- Regular maintenance is required
- Initial setup required highly skilled engineer

2. WHY MATERIAL SELECTION IS REQUIRED FOR SPRAY PAINTING ROBOT?

Spraying work has the characteristics of high labour intensity, high repetition of motion and bad working environment. To increase productivity and liberate workers, industrial robots are applied to the field of spraying. The spray manipulator is a motion system composed of articulated rigid bodies driven by a motor on each joint [3]. The spray coating method is the harmful process in the

painting operation. It causes a lot of dangers to the human workers such as:

- Production of fire during the combination of flammable paint and air.
- Emission of toxic fumes and mist in the environment.
- Possibility of cancer disease.
- Noise from the spray gun nozzle will cause hearing problems.

To get rid of all the above hazards, the spray-painting robot was introduced to perform this process. This robot attaches a spray gun on its wrist and acts like an end effector. The operation is programmed by a human with the help of teaching – through methods. A robot must have several necessities such as two or more program storage, continuous path control, manual lead through programming method, and hydraulic drive system for carrying out this process. This type of robot is mostly used in automobile industries for painting the exterior and interior parts of a car [5].

As a spray-painting robot is working in a crucial environment, before using a robot, some of the significant parameters should be checked for achieving consistent quality of painting like air & fluid pressure, flow rate, specific gravity, viscosity, appropriate temperature, and more. Most importantly, it should be cleaned sequentially for gaining high consistency. Also, material properties for robots should be studied well. Because it should work efficiently in a typical environment and stability and strength should be enough to have better work as well as to avoid vibrations.

2.1 Properties Required for Material of Spray-Painting Robot

Selection of material for robots depends on multiple parameters like design, job to be performed, speed of operation, environment of operation, hazardous materials involved, length of reach, path of travel, process variables, human involvement, controller capability, and result of failures. Robots are mostly built of common materials. Some specialized robots for clean room applications, the space program, or other "high tech" projects may use titanium metal and structural composites of carbon fibres. The operating environment and strength required are major factors in material selection [4].

Steel, cast iron, and aluminium are most often used for the arms and bases of robots. If the robot is mobile, they usually equip them with rubber tires for quiet operation and a positive grip on the floor. Robots contain a significant amount of electronics and wiring, and some are radio or laser controlled. The cylinders and other motion-generating mechanisms contain hydraulic oil or pressurized air. Hoses of silicone, rubber, and braided stainless steel connect these mechanisms to their control valves. To protect the robot from the environment, some exposed areas are covered with flexible neoprene shields and collapsible bellows. Electric motors and linear drives are purchased from automation suppliers along with the controller, or "brain." Controllers are housed in steel electrical cabinets located near the robot's work area or carried on board the robot itself [4].

3. STRUCTURAL DESIGN OF SPRAY-PAINTING ROBOT [2]

The normal spray-painting robot also includes various parts like base, waist parts, driving rocker, connecting rod, small arm, wrist parts, forearm and spray nozzle in the last. We can see from figure 2; the entire stability of the spray-painting robot depends on the rigidity of base. So, base material should be capable enough to carry the entire weight and moment of the robot. We have to find the maximum load that will be available at the end of the robot in the worst condition.

Fig -2: Three-dimensional model of 6-DOF spray painting robot [2]

Generally, the operation of some large work pieces could be completed by many people working together, thus consuming a lot of labour costs. At the same time, the quality of spraying cannot be accurately guaranteed because of some human errors, so a larger workspace is required for spray painting robots. In this paper, a 6-DOF spray-painting robot is designed, as shown in Fig. 1. It mainly includes a base, waist parts, a driving rocker, a connecting rod, a big arm, a small arm, wrist parts, a forearm, a spray nozzle and so on. There are six degrees of freedom, corresponding to these 6 main joints respectively: waist rotation (J1), shoulder pitch (J2), elbow pitch (J3), wrist rotation (J4), wrist pitch (J5), spray nozzle rotation (J6). The robot will drive these six degrees of freedom to complete the job with six independent motors, and the base is used to support the six-joint manipulator. The base is fixed on the ground, with its upper end connected to the waist parts by a flange plate, and its lower end equipped with actuators and driving devices. The

big arm, driving rocker, connecting rod and small arm constitute a four-link mechanism. The arm is driven by the rocker, which can increase the accuracy and stability of the movement. The wrist is the part that connects the arm and the forearm, and the forearm is a moving part that supports the end effector and adjusts its orientation and posture. The material of the upper arm of the painting robot is made of aluminium alloy to reduce the weight and the moment of inertia of each component, thereby improving the stability and dynamics of the robot during movement; and as the base carrying the spraying robot, it requires high rigidity and strength. So, structural steel is selected as the material.

4. SUITABLE MATERIALS FOR SPRAY PAINTING ROBOTS:

For spray painting robots we have to select different materials for different parts. Arm of the robot should be lighter enough. So, overall robot weight can be reduced. And arm movement can also be easy due to this. Similarly, the base is required to have enough strength that it can carry the entire weight of the robot structure as well as it should absorb vibrations. The material of the upper arm of the painting robot can be selected as aluminium alloy to reduce the weight and the moment of inertia of each component, thereby improving the stability and dynamics of the robot during movement and as the base carrying the spraying robot, it requires high rigidity and strength. So, structural steel can be selected as the material.

4.1 Aluminum Alloys

As discussed above, aluminum alloy is best suitable material for robot arm. As it is having enough strength and lightweight. So, it can have speedy movement and robot arm can give fast response with respect to given command to the robot. Various aluminum alloys available are given Table 3.

Because of extensive application in aerospace, automobile and chemical industries the Aluminum alloy is used for experimental work. After studying all aluminum alloys, AA 7075 possesses very high strength and highly stressed structural parts. Applications of AA 7075 are aircraft fittings, shafts, gears, missile parts, defense applications. Main alloying elements of AA 7075 are zinc, magnesium, copper. Detailed composition of AA 7075 is given below.

Table -1: Standard Composition of AA 7075

Element	Weight %
Al	87.1-91.4
Zn	5.1-6.1
Mg	2.1-2.9
Cu	1.2-2
Fe	Max 0.5
Si	Max 0.4
Cr	0.18-0.28
Mn	Max 0.3
Ti	Max 0.2

Table -2: Mechanical Properties of AA 7075

Properties	Value
Density (g/cm^3)	2.81
Poisson's Ratio	0.33
Ultimate Tensile Strength (MPa)	572
Yield Strength (MPa)	503
Elongation (%)	11
Hardness (HV)	175

4.2 Structural Steel

Structural steel is having various grades. All grades have their own properties. Properties for most used grades in industries are describe in given Table 4. Some of the properties for structural steel is described here.

- Characteristics - Structural steel vary from concrete in its attributed compressive strength as well as tensile strength.
- Strength – It has high strength, stiffness, toughness, and ductile properties, structural steel is one of the most commonly used materials in commercial and industrial building construction.
- Constructability – Any shape can be developed from structural steel, which are either bolted or welded together in construction. It can be erected as soon as the materials are delivered on site, whereas concrete must be cured at least 1–2 weeks after pouring before construction can continue, making steel a schedule-friendly construction material.
- Corrosion - Steel, developed a potentially dangerous structure, can corrode when it contacts with water. Measures must be taken in structural steel construction to prevent any lifetime corrosion. The steel can be painted, providing water resistance. Also, the fire resistance material used to envelope steel is commonly water resistant.
- Fire resistance - Steel is inherently a noncombustible material. However, when heated to temperatures seen in a fire scenario, the strength and stiffness of the material is significantly reduced.

Table -3: Various Aluminum Alloys, Their Properties and Typical Applications [6]

Alloy	Formability or Workability	Weldability	Machining	Corrosion Resistance	Heat Treating	Strength	Typical Applications
Alloy 1100	Excellent	Excellent	Good	Excellent	No	Low	Metal Spinning
Alloy 2011	Good	Poor	Excellent	Poor	Yes	High	General Machining
Alloy 2024	Good	Poor	Fair	Poor	Yes	High	Aerospace Application
Alloy 3003	Excellent	Excellent	Good	Good	No	Medium	Chemical Equipment
Alloy 5052	Good	Good	Fair	Excellent	No	Medium	Marine Applications
Alloy 6061	Good	Good	Good	Excellent	Yes	Medium	Structural Applications
Alloy 6063	Good	Good	Fair	Good	Yes	Medium	Architectural Applications
Alloy 7075	Poor	Poor	Fair	Average	Yes	High	Aerospace Applications

Table -4: Most used grades of structural steel in industry and their chemical composition [7]

Grade Designation	Quality	Ladle analysis, Percent, Max					Carbon Equivalent (CE)	Deoxidation Mode
		C	Mn	S	P	Si		
E 250	A	0.23	1.50	0.045	0.045	0.40	0.42	Semi-Killed/Killed
	BR B 0	0.22	1.50	0.045	0.045	0.40	0.41	Semi-Killed/Killed
	C	0.20	1.50	0.040	0.040	0.40	0.39	Killed
E 410	A BR B 0	0.20	1.60	0.045	0.045	0.45	0.50	Semi-Killed/Killed
	C	0.20	1.60	0.045	0.040	0.45	0.50	Killed

5. CONCLUSIONS

As per data mentioned in paper, it is preferable to select arm material as aluminum alloy 7075. We can also use 6061 or 3003 as they can be used for structural applications. But 6061 and 3003 have medium strength compared to 7075 aluminum alloy. Similarly, for base material structural steel of various grades is suitable as per its properties. Steel is tensile. It has a high strength to weight ratio which means it has high strength per unit mass. So, no matter how large the overall structure is, the steel sections will be small and lightweight, unlike other building materials. We can select different grades also as per weight limitation of robot and load capacity required in robot.

Again, these are not the exact final materials. Apart from these materials' other various materials are also available with similar properties. That we can use when cost is not an issue and necessary to use. So, material suggested in this paper can be used as reference, but this may not be the final selection of material for a given typical application.

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We would like to dedicate this paper to our mothers who guided us in every step which we look.

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