JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 10, No. 5, May 2008, p. 1115 - 1119

The development trend of electric motor for robots

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Robots are widely applied for factory automation, manufacturing of liquid crystal and semiconductor, and bio-industry, public utility, medical treatment and so on. This paper introduces the gradual change of the robot structure and the actuator for robots used in industries.

(Received March 13, 2008; accepted May 5, 2008)

Keywords: Electrical motor, Robots, Actuators

1. Introduction

Although it has now become common to refer robots as electric robots, an electric type industrial robot was first announced in Japan in 1974 when hydraulic type robots were the mainstream[(1)].

That was the time, also called as the 1st robot boom era, when many Japanese entrepreneurs were influenced by the lectures of the industrial robot developers of U.S.A and began their entry into the industrial robot business.

Afterwards, during the early years of 1980s, robots were put into use for factory automation and contributed significantly to the improvement of manufacturing efficiency and product quality, which leads to the gradual expansion of the market as well as the gradual development of the robot itself.

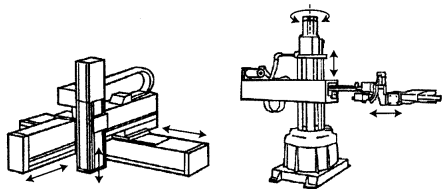
Three major factors, which contributed to the technical recognition of robots in the industrial world, are electrification of the actuator, multi-joint structure of the robot and the emergence of the microprocessor. Rotational drive motor originally had good compatibility with multi-joint robot and the improvement of the performance of the motor and the realization of complex motion control due to the use of microprocessors made it possible to achieve easy-to-use robot movement compared to the rigid movement of multi-joint robots in the past.

Afterwards, the application range of industrial robot was expanded to applications in clean/vacuum environment and, currently becomes indispensable for the development and manufacture of liquid crystal and semiconductor. In addition, from the latter half of 1990s, integration of the information technology (IT) and virtual reality (VR), robot technology (RT) in robotics created new application areas such as in bio-industry, public utility, medical treatment, social welfare, etc., and consequently, further expansion of the market is expected .

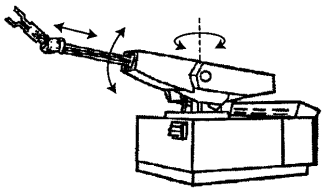
Concentrating mainly on industrial robots, this paper introduces the gradual change of the actuator that played a vital part in the development of the robot. This paper also introduces the gradual change of the structure of the robot, and the required quality of the servo motor for the robot.

2. The Change of robot structure

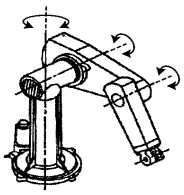
The structure of industrial robot can be broadly classified into the (a) orthogonal coordinates type, (b) cylindrical coordinates type, (c) polar coordinates type, (d) vertical multi-joint type, and (e) horizontal multi-joint (SCARA) type. Fig. 1 shows the schematic image of these robots. Industrial robot initially employed structures of (a) to (c) due to the ease of understanding the tip position intuitively and also because the ease of controllability.



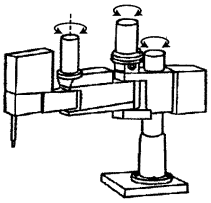
(a) orthogonal coorinate type (b) cylindrical coordinate type



(c) polar coordinate type



(d)vertical multi-joint type



(e) horizonal multi-joit(SCARA)type

Fig. 1. Typical structures of industrial robot.

Afterwards, with the appearance of microprocessors that can handle complex control instantaneously, structure such as (d) and (e) having higher degree of freedom was adopted and it became the mainstream structure afterwards. Moreover, the change in improvement of performance of the actuator is also responsible for such a change in the robot structure.

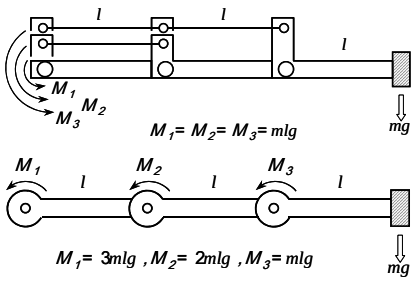


Fig. 2. Arrangement of driving source and necessary torque

Fig. 2 shows the arrangement and the necessary torque of the drive motors of the 3 axes arm mechanism. In case of the parallel arrangement of (a) where the drive motors are arranged at the base of the robot arm, each of the motors have to generate the same torque if the mass of the arm is disregarded. This arrangement was employed in multi-joint robots at a time when the motor was heavy and could generate only a small torque. On the other hand, in the series arrangement of (b) where the drive motors are dispersed to the joints of the robot arm, the torque requirement is different for each of the motors, and the motor closer to the one that is further away from the base torque. Furthermore, in this arrangement, there is no interference of operation by the link mechanism and no decrease in the rigidity resulting in an improvement of the performance of the robot. Moreover, development of servo motor which is small but can generate high torque due to the improvement of permanent magnet characteristics, improvement of the coil space factor due to the core division and the winding method leads to the realization of link less multi-joint robot as shown in Fig. 3.

Fig.3 Examples of link-less vertical revolute robot.

Moreover, the enhancement of performance of the actuator is also responsible for such a change in the robot structure.

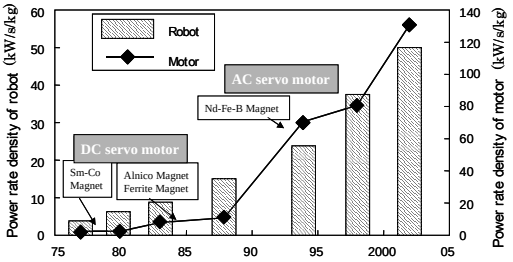


Fig. 4 . Transition of power rate density of robot and motor.

3. Motor and actuators

3.1 Transformation from hydraulic actuators to motor

Initially, oil or pneumatically controlled actuators were used in industrial robots. In addition to the advantage of obtaining large thrust, large stroke, and quick response with simple structures, these actuators were also very small in size as the pressure source equipments were installed separately outside of the actuator body. However, these actuators had the following disadvantages.

· Large space requirement as the pressure source equipment was installed separately from the robot itself.

· Difficulty in piping between the actuator and the pressure source.Frequent maintenance was required due oil or air leakage, etc.

· Running cost was high due to high power consumption.

· Position and force control were difficult.

On the other hand, research on the development of servo motors was started in 1950s in order to overcome the drawbacks of oil/pneumatic actuators and to achieve a high power rate motor structure which leads to the invention of a smooth core armature servo motor in 1958 and an epoch-making DC servo motor with the disk type armature in 1959[(2)]. Electric robot with servo motor as the actuator had the flexibility in combining with other devices and consequently construction of an advanced, coherent system structure became possible which ultimately made these robots to become mainstream industrial robot.

The change of power rate density (power rate divided by the mass of the motor) of servo motor with the change of magnetic characteristics is shown in Figure 4. The change of average power rate density[(3)] of an industrial robot during that period is also shown in Figure 4.

It is understood that the performance of industrial robot improved with the improvement of performance of the motor. Moreover, the disappearance of the brush from the actuator as DC servo motor is replaced by AC servo motor results in the improvement of reliability and maintenance characteristics of the robot. Figure 5 shows a transition of AC servo motor.

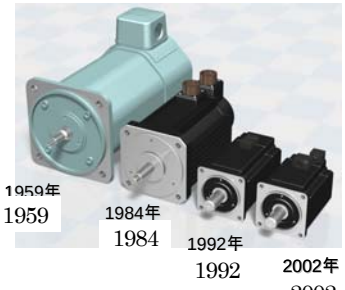


Fig. 5. Transition of servo n...

It is almost the same period when the encoder, used as a positional detector of the motor, started using the absolute method of encoding from the incremental method. As a result, the total positional error in the servo system disappeared theoretically because the starting point returns operation at the commencement of work becomes unnecessary leading to the improvement of reliability of the robot.

3.2 Actuator with built in speed reducers

To drive a robot, rotational speed to the level of several tenths to several hundredths of the usual rotation of a servo motor and a large torque is necessary. To achieve that requirement, actuator with built in speed reducer is used. However, to improve the ratio of the payload to robot mass, and also to develop independent portable type robot, the weight and the size of the actuator becomes very important.

From 1983 to 1990, the Ministry of International Trade and Industry of Japan conducted a large-scale research project titled "Research and development of the advanced robot" and researched on various essential technologies to develop a robot that can operate in an environment which is not safe for human, and one of the result of that research was the development of an actuator with built in speed reducer which is very small and light compared to those available at that time. This actuator was developed to drive the arm and shoulder of a four-foot walking type robot for nuclear power plant and as shown in Fig. 6., the structure of the actuator is a high density assembly of the AC servo motor, the harmonic reduction gear, and the resolver with weight about one tenth compared to actuators available at that time. This actuator also achieved generation of a high torque per unit mass of the actuator (30 ~ 40N· m/kg)[(4)]。

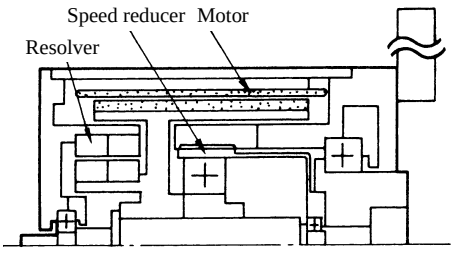


Fig. 6. Cross section of the integrated actuator.

Fig.7 The integrated actuator.

Based on this technology, the development of the next generation robot and both arm assembly robots with joints having 7 axes were announced one after another in 2005. These robots can do complicated and smooth handling like a human. A diagram of the actuator with built-in speed reducer used in these robots is shown in Figure 7. A diagram of the both arm robot is shown in Figure 8. This small actuator was developed based on the construction of the actuator developed in MITI initiated research Project mentioned before and this actuator allowed to achieve a slim robot arm having multi axis composition, by making the axis hollow and using that hollow area as the passage of cable to the servo motor [(5)].

(a) the next generation robots

(b)two-arm robot

Fig. 8. New concept robots using the integrated actuator.

Moreover, a micro, light actuator that generates torque to the level generated by a human finger was developed in the same year. This actuator has the size same as that of a human finger joint[(6)]. The specification of the actuator is shown in Table 1 and the general view of the multi finger hand unit composed of three joints and three fingers by using nine actuators is shown in Figure 9. This study is research and development result in the strategic base technology reinforcement business of Organization for Small & Medium Enterprises and Regional Innovation of Japan.

Table 1. Specification of ultra small integrated actuator.

	Actuator specification
Outside Dimension	φ20×22.7 [mm]
Mass	35 [g]
Peak Torque	0.7 [N·m]
Rated Speed	15 [min^{-1}]
Actuator Structure	Joint Structure
Reduction Gear Type	Flat Harmonic Drive
Reduction Ratio	1 / 120
Encoder Type	Magnetic Encoder

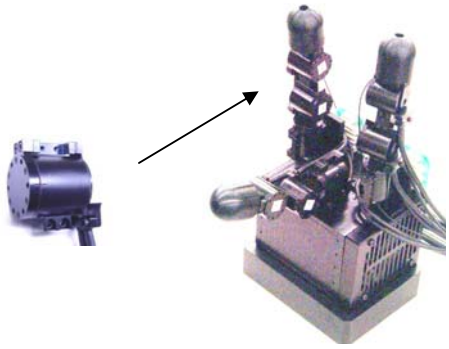


Fig. 9. Ultra-small integrated actuator and multi-fingered hand.

4. Required quality of servo motor for robot

Besides the five typical structures shown in Figure 3, robot has also a special structure like humanoid. Moreover, robot is used in high temperature, high humidity, combustible and dusty environment as well as in clean room and vacuum environment performing tasks like assembly, transportation, and the arc welding, etc.

Although the necessary quality of a servo motor depends on the working condition as well as on the layout arrangement, the common quality requirements of a servo motor are that the motor should be small and

light, the motor should have a sound servo performance and should produce high torque, should have high efficiency and longevity in addition to the following general requirement

· High reliability with a predictable longevity

· Exclusion of substances which are considered harmful to environment.

· Possess the safety mechanism (brake) that ensures the safety when the power supply is interrupted as well as during the emergency.

· Maintenance and the inspection must be easy.

· Withstand vibration and impact from the outside, and have a large thrust and radial load .

· Large line up of models with different capacity so that optimum selection based on the working condition is possible.

Next, the necessary quality of the servo motor based on structural arrangement.

· Multi-joint vertical or horizontal type

To drive the actuator, which is installed on a long arm or in the middle of a long arm, load inertia of the base axis becomes large. The rotor of the servo motor must have appropriate inertia to balance the inertia between loads arm.

· Humanoid type

Due to the multi axis type construction, optimal wiring of the power and the signal line is necessary. Moreover, the maximum output (maximum torque and highest rotational speed) must be high because instantaneous power is required for posture control when it walks.

Again, the necessary specific quality of a servo motor when classified based on usage.

· Assembly robot

Possess a high power rate and power rate density to achieve position accuracy by accelerating and decelerating the payload repeatedly within a specified distance.

· Transportation robot

Possess a continuous output of rated torque and rotational speed, and high output densities due to the heavy payload and long transportation distance.

· Arc welding robot

Cogging and torque ripple must be small to achieve high locus controllability.

On the other hand, the necessary quality of the servo motor when classified based on the environment of its intended application.

· Clean environment

Generation of dust or gas should be kept as low as possible. Since sliding contact parts exist in servo motor, it is not possible to completely eliminate dust generation. However measures should be taken to control the wear or sealing of generated dust or filter and discharging of the exhaust outside.

· Vacuum environment

Sufficient countermeasures must be implemented to keep the generation of dust or gas to a level lower than that required for clean environment Moreover, since discharge of heat by thermal convection is not possible in vacuum environment, cooling of the servo motor by water-cooling or by thermal conduction should be employed.

5. Conclusion

Within a span of less than half a century, robot has rapidly infiltrated in the industrial world. In future, by changing its working pattern and shape steadily, it will continue to infiltrate in areas very close to life of the human being. Simultaneously, The industrial world will accomplish further progress with enhanced performance by utilizing robot, and electromagnetic/ non-electromagnetic electric servo motor will make a major contribution to achieve that.

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