Editorial

Mechatronics: In the Mind's Eye of an Engineer

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1. Introduction

According to a dictionary, the mind's eye refers to the function of a sharp mind to see the truth of things [1]. We tend to think that the products (artifacts) created by technology are what science brings. This is true in a sense, but we should not forget that many products are born in the sensual mind's eye of engineers, which cannot be expressed in words at all. It is said that engineers rely heavily on visual, non-verbal processes for inspiration. Engineering designers are those who can assemble and operate in their minds a new device that does not even exist in the real world [2]. What is important are the images in the mind of those who have come up with a new idea or concept.

The origin of the term “mechatronics” is often misunderstood, although many readers may know that the word was created by a Japanese engineer. This paper first takes a broad look at how the word “mechatronics,” then a brand-new concept, has evolved to the present day. Next, the paper characterizes actuators, which are important components of a mechatronic system, specifically comparing electromagnetic and fluid power types. It also presents the performance of the latest electromagnetic motors for electric vehicles (EVs).

2. Origin of the Term Mechatronics

The term “mechatronics” was coined by Mr. Tetsuro Mori, an engineer at YASKAWA Electric Corporation, in 1969 [3) 4)]. Fig. 1 shows a copy of the invention registration form at that time. The form states the motivation for the invention: “Mechatronics is a composite of 'mecha' from mechanism and 'tronics' from electronics. In other words, the term was invented with the intention of adding more and more 'electronics' to the 'mechanisms' of new products and technologies in order to link the former more closely and organically to the latter.”

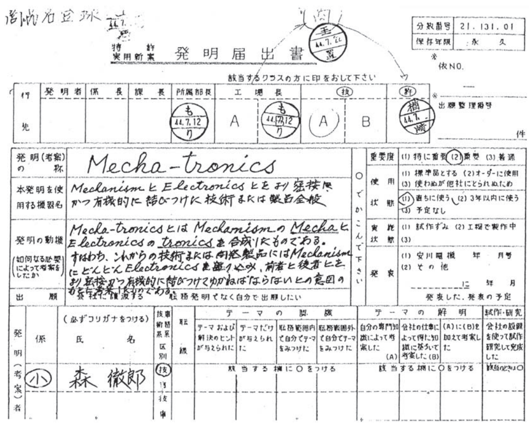

Fig. 1 Invention registration form at that time

It should be noted that the “mecha” of mechatronics comes from mechanism. In fact, many popular books explain that the term “mechatronics” is a combination of mechanics and electronics [5]. I got the same answer when I asked a generative AI (ChatGPT 4o).

Although it is now widely recognized that mechatronics is an interdisciplinary academic field that encompasses mechanical, electrical and electronic, control, computer, and other engineering fields, it has its origins in the fusion of mechanisms and electronics. We should not forget the amazing inspiration and achievement of engineer Tetsuro Mori, who successfully expressed the idea of combining mechanism and electronics in one word, “mechatronics,” which did not exist at that time.

YASKAWA registered the word “mechatronics” as a trademark in 1972. Fig. 2 shows an excerpt from the trademark gazette by the Japan Patent Office [6]. Another important point in this matter is that YASKAWA later abandoned the trademark in 1978, attaching importance to the possible spread of the word in the market, thus releasing the trademark rights. As a result, the original

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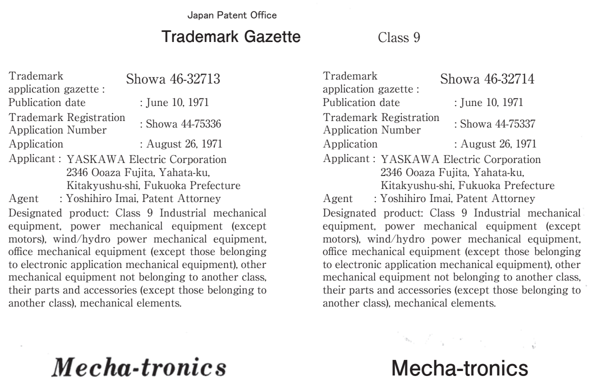
Japanese word "mechatronics," a kind of Japanese English, has been recognized throughout the world since the 1980s. The concept became popular along with the word. In 1996, the Institute of Electrical and Electronics Engineers (IEEE), which is an organization for researchers in the field of U.S. information telecommunications engineering, and the American Society of Mechanical Engineers (ASME), which is an organization for researchers in the field of U.S. mechanical engineering, jointly published the IEEE/ASME Transactions on Mechatronics [7], thereby formally recognizing the Japanese English word "mechatronics" in the world. In the same year, the 1st International Conference on Mechatronics Technology (ICMT1996) was held in the U.S. Since then, the conference has been held every year mainly across Asia-Pacific. Kanazawa, Japan hosted the 27th conference in November 2024, and Hanoi, Vietnam plans to host the next one in 2025, with the participation of many engineers and researchers, including Japanese.


Japan Patent Office

Trademark Gazette Class 9

Trademark application gazette : Showa 46-32713
Publication date : June 10, 1971
Trademark Registration Application Number : Showa 44-75336
Application : August 26, 1971
Applicant : YASKAWA Electric Corporation
2346 Ooaza Fujita, Yahata-ku, Kitakyushu-shi, Fukuoka Prefecture
Agent : Yoshihiro Imai, Patent Attorney
Designated product: Class 9 Industrial mechanical equipment, power mechanical equipment (except motors), wind/hydro power mechanical equipment, office mechanical equipment (except those belonging to electronic application mechanical equipment), other mechanical equipment not belonging to another class, their parts and accessories (except those belonging to another class), mechanical elements.

Mecha-tronics

Trademark application gazette : Showa 46-32714
Publication date : June 10, 1971
Trademark Registration Application Number : Showa 44-75337
Application : August 26, 1971
Applicant : YASKAWA Electric Corporation
2346 Ooaza Fujita, Yahata-ku, Kitakyushu-shi, Fukuoka Prefecture
Agent : Yoshihiro Imai, Patent Attorney
Designated product: Class 9 Industrial mechanical equipment, power mechanical equipment (except motors), wind/hydro power mechanical equipment, office mechanical equipment (except those belonging to electronic application mechanical equipment), other mechanical equipment not belonging to another class, their parts and accessories (except those belonging to another class), mechanical elements.

Mecha-tronics

Fig. 2 Trademark gazette

In the 2000s, the concept of mechatronics was widely used in engineering and industrial products. As the term became a more common concept, it became less necessary to use the word mechatronics specifically.

As described above, the word mechatronics, originally proposed by a Japanese engineer, has now spread throughout the world. I would like to pay my respects once again to the mind's eye of the Japanese engineer Tetsuro Mori.

3. Mechatronic System Configuration

In my lectures, I usually use the block diagram shown in Fig. 3 to explain the concept of mechatronics. A mechatronic system consists of five subsystems: a computer, actuators, a mechanism, sensors, and energy sources. Each subsystem can be compared to a corresponding organ or function in the human body.

This configuration can be applied to a specific servo system for positioning a degree-of-freedom load system consisting of a spring, mass, and damper with a hydraulic cylinder, as shown in Fig. 4. The actuator here consists of a hydraulic servo valve and a hydraulic cylinder. In this servo system, position and load status data is fed back from sensors to the computer, where a software-based controller sends commands to the servo amplifier according to the setpoints. The servo amplifier converts and amplifies the electrical energy supplied by the power source to drive the electromagnetic motor on the first stage of the

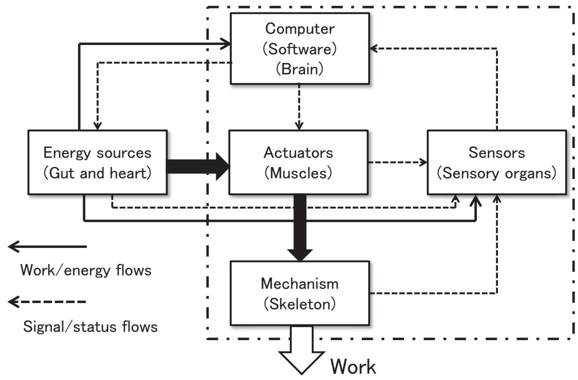


Fig. 3 Mechatronic system configuration

hydraulic servo valve. It also converts and amplifies the hydraulic energy supplied by the hydraulic source to drive the spool valve on the second stage, enabling the hydraulic cylinder to perform the specified positioning according to the setpoints. The fact that actuators and a mechanism are key components of a mechatronic system to achieve the desired work is also evident from these two block diagrams.

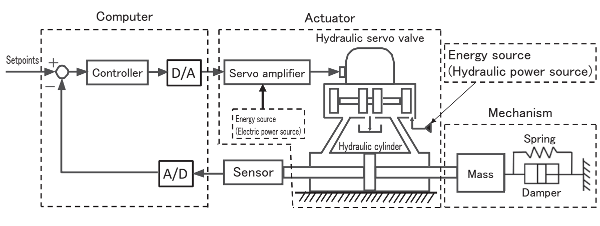


Fig. 4 Inertial load positioning servo system with hydraulic actuator

4. Actuator Performance Comparison

The actuator plays a critical role in the mechatronic system configuration shown in Fig. 3. The performance of the system is almost entirely determined by the performance of the actuator. A mechatronic system with a high-power, high-response actuator can provide high performance.

Conventional actuators can be classified by drive method into electromagnetic type, typified by AC/DC motors, and fluid power type, typified by hydraulic motors. This paper compares the performance of a commercially available electric servo, as an example of a rotary actuator, and a hydraulic piston motor.

With the mass of the actuator m [kg] and the rated power P_r [W], the power density P_d [W/kg] (power per unit mass) can be defined by the equation:

$$P_d = \frac{P_r}{m}$$

Power density is a performance measure of compactness, light weight, and high power. Engineers may set a goal to design an actuator with low mass and high power density.

Fig. 5 shows the results of a study by Sakama et al. [8] on the power density of commercially available actuators. Red triangles represent AC servo motors, orange triangles represent brushless DC motors, yellow triangles represent brushed DC motors, green circles represent swash plate-type or bent axis-type hydraulic axial piston motors, and green squares represent hydraulic radial piston motors.

In the figure, the three types of motors, namely AC servo motors, DC servo motors, and hydraulic piston motors, occupy their own area with almost no overlap, except for the red-framed area. The figure also shows that hydraulic piston motors have higher power density than AC servo motors of the same mass range. In addition, the majority of hydraulic piston motors are large, with a mass of 10 kg or more, while some of them are small, with a mass of 1 kg or less. The market for small hydraulic motors of 1 kg or less may not be large due to limited applications or structural constraints. However, the development of such hydraulic actuators of this size may have the potential to find a new market in the future.

The automotive drive system has recently shifted from internal combustion engines to electric motors. As the automotive actuator has shifted in response, an innovative movement has been seen in electromagnetic rotary actuators [9].

One example is YASA Ltd. [10] [11]. The company has developed an axial flux motor with a different operating principle from the traditional one and has used the motor in Mercedes-Benz sports EVs and Lamborghini EV supercars. According to my calculation using available data, this motor, which weighs 24 kg, has a power density of 6.67 kW/kg, which is incredible for electromagnetic motors. This motor is not a servo motor, but its performance could be plotted in Fig. 5. The motor then shows the performance indicated by the red dot, which is well within the range of hydraulic motors. This remarkable performance was probably achieved with an innovative technology

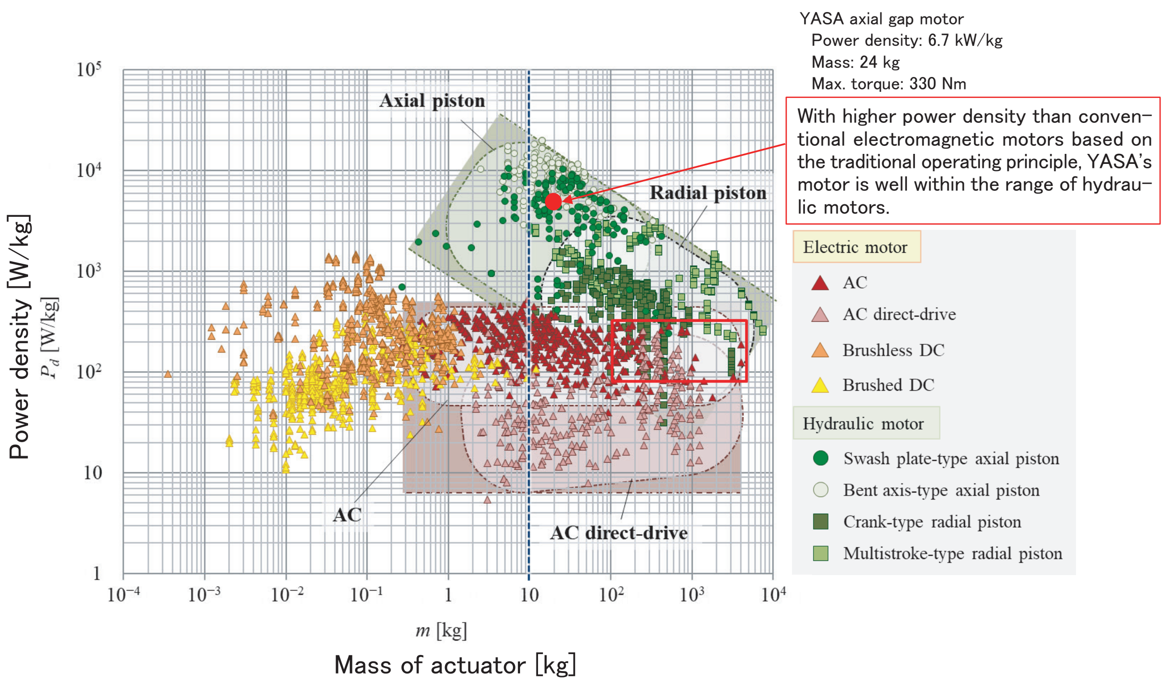


Fig. 5 Performance comparison between electromagnetic and hydraulic actuators

that was not developed by sticking to traditional principles. For your information, the person who developed and commercialized this electromagnetic motor after overcoming many difficulties was Dr. Tim Woolmer, who founded YASA after leaving the University of Oxford in the United Kingdom. He is also the kind of person with a mind's eye.

5. In Closing

This paper has taken a broad look at how the concept of mechatronics has evolved to the present day and has pointed out that the actuator is the key component of the mechatronic system. It has also compared and evaluated the performance of hydraulic and electromagnetic actuators in terms of power density.

Ahead of the rest of the world, Japan is already experiencing the common challenges of mankind, including a declining birthrate and aging population, energy problems, environmental issues, and natural disasters. I sincerely hope that the readers of this paper will be engineers with a mind's eye who can propose and provide new solutions with advanced mechatronics technology to help tackle these challenges from Japan in the midst of the rough and tumble of globalization, just as a Japanese engineer introduced the concept and word of mechatronics, a composite of mechanism and electronics, to the world 56 years ago.

References

1) SHOGAKUKAN Inc.: "Digital Dai-ji-sen."
2) E.S., Ferguson: "Engineering and the Mind's Eye," Japanese translation by FUJIWARA, SUNADA, Heibonsha, 1995.
3) YASKAWA Electric Corporation website: https://www.yaskawa.co.jp/milestones/1960s#01 (accessed on January 6, 2025).
4) MORI Tetsuro: "Mecha-tronics," Yaskawa Internal Trademark Application Memo. 21.131.01, July 12, 1969.
5) For example, SHIBUYA Koji: "Basics of Mechatronics (2nd Edition)," Morikita Publishing Co., Ltd., June 30, 2023.
6) Trademark Gazette Showa 46-032713 and 46-32714, Trademark Registration 0946593 and 0946594 (Japan Platform for Patent Information, accessed on January 6, 2024).
7) KYURA N, OHO H: "Mechatronics - An Industrial Perspective," Trans. Mechatronics, Vol.1, No.1, pp.10-15, March 1996.
8) SAKAMA S, TANAKA Y, KAMIMURA A: "Characteristics of Hydraulic and Electric Servo Motor," Actuators, 11, 11, 2022.
9) K. Deepak, M.A. Frikha, Y. Benômar, M. El Baghdadi, O. Hegazy: "In-Wheel Motor Drive Systems for Electric Vehicles: State of the Art, Challenges, and Future Trends," Energies, 16, 3121, 2023.
10) D. Zhu, B. Peng and C. Wang: "Comparison of Performance of YASA Axial Flux Permanent Magnet Motor with Interior Tangential Rotor and Sticker Rotor," 2023 3rd Asia-Pacific Conference on Communications Technology and Computer Science (ACCTCS), Shenyang, China, pp.433-437, 2023.
11) YASA website: https://yasa.com/ (accessed on January 6, 2025).