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1 March 1982

Japan Report

(FOUO 14/82)

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JAPAN REPORT

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POLITICAL AND SOCIOLOGICAL

STATEMENT BY FORMER PREMIER KISHI

Tokyo MAINICHI DAILY NEWS in English 28 Jan 82 p 2

[Article by Takehiko Takahashi]

[Text] Former Prime Minister Nobusuke Kishi became a supreme adviser to the Liberal-Democratic Party at the party convention held on Jan. 21.

There have been four supreme advisers up to now -- Takeo Miki, Takeo Fukuda, Hirokichi Nadao and Ken Yasui. These four have had the experience of either being the prime minister or speaker of the House of Representatives or president of the House of Councillors. They are still active Diet members.

Being an active Diet member had been a condition attached to becoming a supreme adviser. This condition has been waived in making Kishi a supreme adviser.

The situation within the LDP made it necessary for the party regulations to be revised in order to make Kishi a supreme adviser. Since the operation of the LDP is grasped by the Tanaka faction, former Prime Minister Fukuda urged LDP President Zenko Suzuki to set up a vice president between the president and secretary general. At one time Prime Minister Suzuki considered doing this but opposition rose from the Tanaka faction.

What Suzuki thought of next was to make Kishi, who is Fukuda's boss, a supreme adviser. Fukuda could not object to this and since Kishi is on friendly terms with Kakuei Tanaka, the Tanaka faction could not oppose it. In this way the idea of having a vice president was shelved and party harmony was preserved.

Kishi is 85 years old. On Jan. 21, the day when he became the supreme adviser, he attended a meeting of financial leaders and said, "there is a saying 'eternal youth and longevity.' In this respect, I would like to live actively without my mind becoming senile."

Non-Political

He added, "I would like to remain uninvolved in hectic political affairs and will try to keep my mouth shut."

At this meeting, Kishi was asked:

"Upon looking at the present financial and economic situation, 'financial rehabilitation without a tax increase,' which the prime minister has repeatedly mentioned, appears impossible. In drafting the budget for the next fiscal year, a choice will probably become necessary between a tax increase and a change of the financial rehabilitation plan. In that case, Prime Minister Suzuki will become unable to carry out the 'administrative reform' and 'financial rehabilitation without a tax increase,' on which he has staked his political career. If that happens, will the prime minister have to assume political responsibility?"

In reply to this question, Kishi answered with a very ordinary expression:

"Speaking from the standpoint of common sense, the prime minister should take political responsibility."

But Kishi added:

"I do not know whether Prime Minister Suzuki will do so or not. He may not take responsibility and resign because of the reason, 'what would happen if I were to resign?' Even then, as a general principle, he should assume political responsibility and resign in such a case. This remains unchanged."

Finance Minister Michio Watanabe hinted on Jan. 22 at a change of the financial rehabilitation plan. His replies to interpellations in the Diet have indicated, however, that he intends to carry out the financial rehabilitation as scheduled. This is necessary in order to reject the demands being made by the opposition parties for a reduction of the income tax.

Director General Toshio Komoto of the Economic Planning Agency has the thought that domestic consumption can be stimulated by an income tax reduction. The way of thinking of Chairman Rokusuke Tanaka of the LDP Political Affairs Research Council is close to that of Komoto.

Opinions are prevalent in the Liberal-Democratic Party that "even if it is possible to shelve an income tax reduction this year, it will be necessary to carry it out in the next fiscal year." It is felt that an income tax reduction is essential as election countermeasures when the unified local elections and House of Councillors election take place next year.

Financial Rehabilitation

If the income tax is reduced, it will be necessary to cover this in some way with an increase of other taxes. This will affect the "financial rehabilitation without a tax increase" plan. Even if there is a tax increase, it may be necessary, depending on business trends, to alter the financial rehabilitation plan (the issuance of deficit national bonds to be zero in the fiscal year 1984).

The situation will become clearer in the discussions on the budget in the ordinary Diet session and again in the stage of budget compilation for the next fiscal year.

How will Kishi's words that "speaking from the standpoint of common sense, the prime minister should take political responsiblity" be borne out?

The political world is likely to be filled with constant tension from now on.

CSO: 4120/146

POLITICAL AND SOCIOLOGICAL

FUKUDA FORESEES TURMOIL

Tokyo THE JAPAN ECONOMIC JOURNAL in English Vol 20, No 992, 9 Feb 82 p 10

[Article by Masao Kanazashi]

[Text]

Beset by a covey of knotty problems, both of domestic and international nature, Japanese politics seems in for a rough course this year. Takeo Fukuda, former prime minister and one of the biggest leaders in the ruling Liberal Democratic Party, says that 1982 will be a year of great turmoils. Fukuda recently talked with Masao Kanazashi, senior staff writer of the Nihon Keizai Shimbun. The highlights of the interview are as follows:

Kanazashi: You say that 1982 will be a year of great turmoils

Fukuda: The world situation will be far from quiet today, and there is no immediate signs that the situation will improve. With the sole exception of Japan, countries all over the world are suffering from inflation and unemployment. I have serious fears about the future of the world economy. I feel my hair standing on end just by thinking about what will happen in the world.

The current economic confusion is not merely a phase of an economic cycle but a dire result of the oil crises. Man now finds himself squarely confronted, for the first time in history, with the fact that natural resources are by no means inexhaustible. The world population, on the other hand, has been growing at an almost explosive tempo and is expected to easily top the 6 billion mark by the end of the current century. Man is no longer in a position to uphold the mass cunsumption practice it has come to be so used to in the post-war years. We have to understand the present worldwide confusion as part of a momentous change man is now going through.

Q: You say that any large-scale revenue shortfalls, if they develop, will lead to a political crisis...

A: Some say that the 5.2 per cent economic growth projected by the Government for the new fiscal year is too high. As long as the Government has set up that target, however, it should do its best to attain it, although the Japanese people are usually gracious enough to accept some margin of error. Revenue shortfalls are completely different in nature from some innocent errors in economic forecasts. Public finances are another name for national budget and, therefore, are directly related to politics. What I meant is that problems in public finances, therefore, will naturally be treated as political problems. If tax revenues record unexpected declines, many will naturally wonder what will become of administrative reforms and reconstruction of public finances.

Q: There are serious trade frictions between Japan and the United States.

A: I don't think that the most basic problem existing between Japan and the United States is trade frictions. The most basic problem is what political attitude Japan will take vis-a-vis the United States, the very mainstay of the Free World. The United States is irritated at Japan's willy-nilly attitude in the face of exceptionally tight international situation. The United States wants Japan to play its role as a member of the Western camp. The Suzuki-Reagan talks held last May must have centered around this all-important problem. The problem of trade frictions is on a slightly lower level of importance.

Even so, there is no denying that trade frictions are pretty bothersome. What should we do about it? In a nutshell, both countries should cast away their protectionistic vestiges. The Suzuki Administration should be more daring in its open-door policy. The United States, on its part, should take stronger measures to overcome its inflation. Unless the Americans do not really try in this field, there will be no major improvements in its trade relations with Japan. Japan should not make any sweet-sounding promises but it should open its market as wide as possible.

Q: Restration of the people's confidence in politics must be the first step in solving a series of knotty problems confronting Japan. Don't you think that there is something the matter with Japan's politics today?

A: Few Liberal Democrats are complacent enough to give full marks to today's politics. It is only natural under the circumstances that the general public should be very much worried about the present political state. Administrative and financial reforms are of utmost importance, it is true, but political reforms are even more important. We have to seriously tackle political reforms before anything else.

Q: Many expect you to play the role of a clean-up man.

A: I will not plunge myself into everyday affairs. My sincere hope is that Prime Minister Zenko Suzuki will try his best to cleanse politics of obnoxious impurities.

CSO: 4120/148

POLITICAL AND SOCIOLOGICAL

TANAKA FACTION EXPANDS

Tokyo THE DAILY YOMIURI in English 29 Jan 82 p 3

[Article by Kenji Kitahara]

[Text] There is a growing belief that former premier Kakuei Tanaka will be found guilty in the Lockheed payoff trials because of recent convictions but this has not dampened the drive of his faction to increase its strength in the Liberal-Democratic Party (LDP).

First Kenji Osano, Tanaka's close friend, was found guilty and this week Tokuji Wakasa, All Nippon Airways (ANA) chairman, was found guilty. There are many Japanese who wonder how Tanaka can maintain his influence and even increase it under the circumstances.

The fact that Tanaka retains powerful political influence even though he is undergoing trial is even more baffling to foreigners.

In fact, the US congressmen who visited Japan in early January for talks on the bilateral trade and security problems never failed to ask how Tanaka could continue to be such a strong man in Japanese politics.

Tanaka, who was forced to step down as premier after being battered with questions on his dark financial dealings at the Foreign Correspondents' Club of Japan, recently has been granting interviews to foreign newsmen.

Tanaka usually gives the following three reasons why his faction continues to expand:

- The Tanaka faction is a kind of comprehensive hospital which is staffed by experts in finance, foreign policy, defense, elections, and political funds, and so the faction helps members greatly,
- Tanaka is indifferent to worldly gain and is eager only to promote his members, and
- In his 35-years as a politician, he has made many friends.

He boasts that his faction could have as many as 150 Diet members if he wished, and that a number of Dietmen soon will enlist in his faction.

Tanaka's explanations reveal part of the truth but not all of it.

Intraparty observers say that Tanaka is really interested in expanding his faction with an overwhelming number of Dietmen to overcome somehow a court verdict against him and that this movement could split the LDP in the future.

Tanaka believes politics is everything and decides everything. Therefore, he equates his trial in the Lockheed case to the trials of the Gang of Four in China and Kim Dae Jung in South Korea.

Hence he wants his judgment handed down against a background of his overwhelming political power supported by strong ranks of Dietmen within his faction.

He seems to have begun preparing for a ruling party split after reflecting upon the 40-day intraparty strife of 1979 and the passing of a no-confidence motion against the late prime minister Ohira in 1980.

Susumu Nikaido, secretary-general of the LDP and a Tanaka man, has established close contacts with middle-of-the-road parties such as the Komeito and Democratic-Socialist Party (DSP) which share common security and foreign policy views with the LDP. This Tanaka has ordered Nikaido to do, apparently to prepare for a coalition government if the LDP splits.

This gives a pure political reason for the expansion of the Tanaka faction.

Of course, Tanaka probably wants to expand his power because of his worries and irritations as well.

It is true that the more friends one has, the safer one feels. But how true are his friends and will they be friends when the court gives its verdict on Tanaka, which is expected within this year if all goes according to plan.

CSO: 4120/148

POLITICAL AND SOCIOLOGICAL

REMOVAL OF NONTARIFF BARRIERS VIEWED

Tokyo MAINICHI DAILY NEWS in English 1 Feb 82 p 2

[Editorial]

The strict, complicated procedures of import inspection and approval, known as nontariff barriers, have been obstructing the smooth flow of goods from foreign countries, so the ruling Liberal-Democratic Party formed a Special Committee for International Economic Measures to work on improving the situation. Saturday, the government of Prime Minister Zenko Suzuki, during the economic cabinet ministers' conference, formally approved the committee's recommendations.

Accordingly, 67 out of about 100 nontariff barriers have been lifted in accordance with the requests of Japan's trading partners, who also called for an easing of import testing procedures. Upon looking at the list of items, we wonder why the government waited until foreign pressure had intensified before taking action.

The decision is an important first step toward opening further Japanese markets to foreign products. The economic ministers also approved the LDP proposal on opening an office to assist in the settlement of grievances related to the openness of Japanese markets — the Office of Trade Ombudsman, OTO — with the deputy chief cabinet secretary as its head in order to ensure the quick and adequate disposal of grievances.

The Japanese government earlier decided to implement the tariff rate reduction plans agreed on during the Tokyo Round of multilateral trade talks two years ahead of schedule. We hope that the United States and European countries will appreciate Japan's efforts to open its market.

We must understand, however, that the easing of import approval measures will only result in a modest increase of imports amounting to about $500 or $600 million a year. Compared with the $18-billion U.S. trade deficit and the $10-billion European

Community (EC) trade deficit with Japan last year, this amount is so negligible it can be compared to a mere drop in the bucket.

Thus, we have to expect the trade friction to continue. We know that balance in trade should not be equally settled between the two nations concerned. If such efforts were pursued, world trade would decline unfavorably affecting the people to a considerable degree. At the same time, we must be aware that the high unemployment rate — about 9 percent — in the U.S. and some European nations is attributed to the large deficits in trade with Japan, and is a political problem.

As a second step toward removing Japan's nontariff barriers, other countries are expected to demand the abolition of residual import restrictions on such agricultural products as oranges and beef, an improvement of our distribution system, and access to financial and other service fields. Japan must respond favorably to these demands.

Japan must try to improve the productivity of these fields by exposing them to international competition. At the very least, efforts must be made to increase the import quota of these products upon expiration of the current import restriction agreement.

From our side we would like to make some strong requests to the United States and European nations. These nations should remember that their enormous trade deficits with Japan basically will not be rectified without strengthening their competitive power in the international market. In this respect, U.S. President Ronald Reagan's policy to expand America's military strength will hinder the reactivation of American industry as a whole. In the U.S. congressional report on U.S.-Japanese trade relations disclosed last year-end, it was pointed out that the majority of U.S. government research and development expenditures are being used for military purposes which is not contributing toward strengthening its international competitive power.

In his State of the Union message, Reagan said he would not resort to a tax increase to offset the fiscal deficits. But we know that the gigantic deficits caused the high interest rates in the U.S. and the relatively high value of the dollar to the yen, and brought about a deterioration of its trade balance with Japan. We urge the Japanese government, which is trying to avoid intensified trade friction, to seek a revision of Reagan's military expansionist policy.

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POLITICAL AND SOCIOLOGICAL

DISCLOSURE OF ARMS DEVELOPMENT MEMO URGED

Tokyo MAINICHI DAILY NEWS in English 31 Jan 82 p 2

[Text] We have learned that the Japanese Defense Agency and the U.S. Defense Department exchanged a memorandum on the joint research and development of weapons in June 1966. The existence of the memorandum was disclosed in a defense magazine article in October 1980 by a professor of the Defense Academy and was recently confirmed by the Defense Agency.

In regard to the content of the memorandum, Defense Agency officials said that it was nothing but a memorandum recording the exchange of views among experts and added that they were studying the possibility of publicly disclosing it. We strongly hope that the content will be disclosed.

We demand the disclosure because we believe that the contents seem to be closely related with the military technology exchange program between Japan and the United States, which is being discussed among the officials concerned, and also the three principles on the ban of Japanese arms exports. We have heard that the Defense Agency and the Foreign Ministry want to promote arms technology exports to the United States but the Ministry of International Trade and Industry is reluctant to do so.

If such an agreement exists, we can surmise that the United States and Japan earlier paved the way for the bilateral exchange of military technology. Japanese and American officials reached an agreement in December last year for their joint efforts to conduct research and development. What are the relations between the said agreement and the latest agreement?

According to the article, the memorandum said: 1) weapons to be developed would be limited to those which are required by the U.S. Army, Navy and Air Force; 2) the two countries would equally share the development expenses; and 3) patent rights and rights to possess know-how resulting from research and development would in principle belong to the United States. If this is true, the memorandum one-sidedly favors the United States.

The three principles banning arms exports were established in February 1967 by Prime Minister Eisaku Sato who pledged in his Diet statement that Japan would not export weapons to the communist bloc and countries engaged in military conflicts. In February 1976, Prime Minister Takeo Miki expanded the sphere of the principles when he said that Japan would refrain from exporting arms to areas hitherto not covered by the principles.

The memorandum was exchanged between Japanese and U.S. officials well before the coming into force of the three principles. Does the memorandum have binding power from the viewpoint of diplomatic interest and obligation? What is the relation between Article 1 of the U.S.-Japan Mutual Defense Treaty, which is believed to be the base enabling the exchange of governmental military material and information, and this memorandum? Many points remain obscure.

Moreover, we are strongly impressed by the Defense Agency's apparent determination to go it alone in disregard of the various disputes in Japan since the United States sought Japan's offer of military technology in June last year.

Needless to say, Japan's national policy is to follow the path of a peace-loving nation and the three principles banning arms exports, together with the three nonnuclear principles, are the basic policy to clearly show Japan's determination to the world. The United States may make strong requests on this specific issue but it is the Japanese people who must decide Japan's own policy and the Defense Agency must have talks with U.S. officials within the limit of the Japanese policy.

In particular, defense problems will become important disputes between the government party and opposition parties in the current Diet session. Accordingly, the government must be prudent in having talks with the United States.

Everybody will agree that, in an open society, disputes on national defense must be conducted in a fair manner. This is a salutary way in democracy. Problems related with the removal of the arms exports ban to the United States have attracted attention not only from politicians but also from the general public. We renew our request for the Defense Agency to publicly disclose the memorandum.

CSO: 4120/148

SCIENCE AND TECHNOLOGY

MECHANISM, CONTROL OF INDUSTRIAL INTELLIGENT ROBOTS INTRODUCED

Hitachi Basic Concept

Tokyo KIKAI SEKKEI in Japanese Vol 25 No 12, Oct 81 pp 64-68

[Article by Shimon Ando* and A. Tsuchihashi**, Hitachi Ltd]

[Text] Intelligent industrial robots have been manufactured on the basis of the basic concept that a robot can work independently using its own intelligence in computation and search after a man gives the robot information essential for the work. The robot under discussion possesses principal functions such as rectangular coordinate guidance by man, line interpolation, search and generation of locus. Also, it can weld or paint by the organic combination of these functions.

An intelligent robot, in particular, among the industrial robots shows promise as a labor-saving machine for automation suitable for a multiproduct small quantity production line in need of complicated and diversified work that is too difficult for a conventional special purpose automatic machine. To meet the needs, development of a so-called independent intelligent industrial robot is greatly desired, one that understands the work content by itself and works without the assistance of a man.

The capabilities of computers which can be used for industrial robots are limited from the aspect of cost. The control technology and the mechanical parts used in them based on the currently available technological level are insufficient for the ideal intelligent robot.

Within thse limited conditions, we have explored the possibility of creating an industrial intelligent robot capable of future growth and realizable at the present technological level, and have already succeeded in manufacturing a welding robot and a painting robot, although the current intelligence level may not be fully satisfactory.

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In this article, we would like to explain the basic concept behind the development of these industrial intelligent robots, as well as the mechanisms, controls and designed basic functions, and their combination for the realization of the robot.

Basic Concept

As shown in Figure 1, when guiding the target point of the robot's hand (welding torch) along a locus (welding line), the locus shown by a broken line is approximated by a chain of straight lines that connect the space between checkpoints. If the robot can move independently on the basis of its own arithmetic control between the checkpoints by line interpolation, the only instruction man has to give the robot is position information, such as the position at checkpoints and postures.

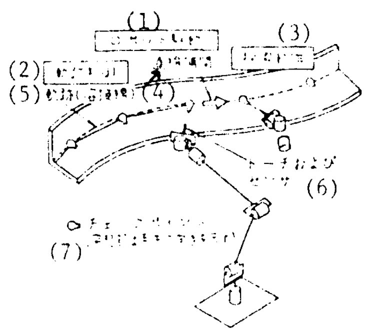


Figure 1. Basic Concept of Control Software for This Robot

Key:

(1) driving of robot
(2) locus control
(3) search action
(4) line interpolation
(5) locus (welding line)
(6) torch and sensor
(7) checkpoint (projection gives direction for the hand)

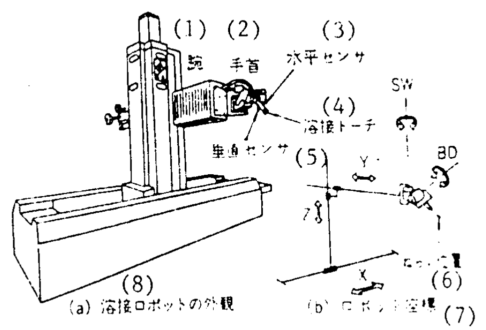
The position information at the check points can be taught by letting a man-guided robot read out the position information. However, this information can be searched out by the robot itself using a distance sensor, or better still, the robot itself can determine the locus and move without being taught by man. Also, the teaching process can be omitted if the checkpoint position information can be computed.

Communication between man and robot will be centered around checkpoints if the man gives position information and an action order at checkpoints, and leaves action between the checkpoints to the robot.

If the robot can search for the position information and instructions for action at the checkpoints by itself or can obtain them by calculation, instructions by man become unnecessary to that extent, and independence can be enhanced. Our objective is the promotion of independence, i.e., what is called intelligence, in regard to the robot, by the invention of various search and computation methods.

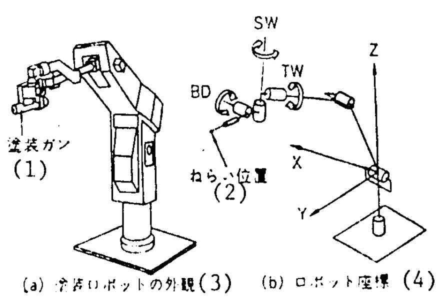
Coordinate Arrangement of Robot Proper

Figures 2 and 3 indicate the external appearance and coordinates of a rectangular coordinate arc-welding robot, Mr Aros, and of a multijoint coordinate painting robot developed as an intelligent industrial robot, respectively. The industrial robot's required performance and functions differ widely depending on the type of work, which results in the practice of adopting a coordinate system that suits the design. For instance, for arc welding of box structured construction machine parts, a rectangular coordinate robot as shown in Figure 2 is employed, as a slow but highly accurate operation is required, whereas the multijoint coordinate robot shown in Figure 3 is used for painting speedily and as extensively as possible in a small painting booth.



Key:
(1) arm
(2) wrist
(3) horizontal sensor
(4) welding torch
(5) vertical sensor
(6) target position
(7) external appearance of welding robot
(8) robot coordinates

Figure 2. Mr Aros, Rectangular Coordinate Welding Robot



Key:
(1) painting gun
(2) target position
(3) external appearance of painting robot
(4) robot coordinates

Figure 3. Multijoint Painting Robot

The coordinate system of the robot will be also affected by oil pressure, electric driving methods, and the elements of the harmonic drive mechanism and link mechanism, but to date what affects it most is the computer. Complex and high-speed arithmetic processing is required to drive a multijoint robot at high speed by arithmetic control. A multijoint robot that serves as an intelligent robot was realized at last due to the progress in highly efficient microcomputers. The coordinate arrangement of robots will also be greatly affected by the competence of the computers to be used for robot control in the days to come. For your information, the specifications for a welding robot and a painting robot are given in Tables 1 and 2, respectively.

Table 1. Standard Specifications for Welding Robot Mr Aros

Item				Stroke	Speed (mm/min)	Fast operation (mm/min)
robot proper	arm	vertical	(Z)	1,300 mm	70∼700	8,000
		horizontal	(Y)	1,100 mm	"	"
		sideways	(X)	2,000 mm	"	"
		sway	(SW)	±90 °	"	"
	wrist	bend	(BD)	-5∼50° (from directly below)	"	2,000
	position reproduction accuracy			±1.0 mm		
	oil pressure source			normal pressure 70 g/cm^2, flow rate 21 liters/min, tank capacity 100 "		
	air source			above 4 kg/cm^2		
	required floor area			1,380 x 4,690 mm		
	weight			1,500 kg (robot proper)		
control unit	driving system			electric-oil pressure servo		
	control system			PTP (point-to-point) teaching system CP control		
	arithmetic function			spot simulation calculation, corner position continuous calculation, corner position automatic production		
	external symbol			38 symbols (8 for welding condition selection, 6 for welding speed selection, 7 for positioner stop point selection and 17 for others)		
	memory capacity			512 steps		
	automatic correction of position information			PTP corrects at each recording point CP corrects space by space		
	power source			200V (±10 percent) 3 phases 50/60 Hz 35kVA 100V (±10 percent) 50/60 Hz 2.5 kVA		

Notes: 1. Weaving function
2. Caterpillar protective cover

Table 2. Standard Specifications for Painting Robot

		Item	Specifications
robot proper	work range	arm, swivel	100° (2,850 mm)
		arm, up and down	2,500 mm
		arm, to and fro	1,200 mm
		sway of wrist	210°
		bend of wrist	210°
		twist of wrist	180°
	speed		Max 1,750 mm/s
	oil pressure source		normal pressure 105 kg/cm^2, flow rate 29 ℓ/min
	power source		AC 200 V (±10 percent), three phases 50/60 Hz 10 kVA
	weight		approximately 500 kg
control unit	driving system		electric oil pressure servo
	control system		CP control by PTP (point-to-point) teaching system)
	arithmetic function		multijoint coordinates and rectangular coordinates conversion calculation, wrist correction calculation, line speed control calculation, conveyer synchronous calculation
	memory system		core memory 4k (16)
	teaching system		remote teaching by teaching box
	program selection		four programs
	external synchronous signal		seven circuits each for transmission, reception
	power source		AC 100 V (±10 percent), 50/60 Hz 1 kVA

Control Unit

Figure 4 gives a block chart of the control unit for welding and painting robots. An 8-bit or 16-bit microcomputer is the central structure of the control. Sixteen-bit action directives are output through the servo interface to each shaft of the robot, and the position of each shaft of the robot is input through the interface by detection using a potentiometer. When a multijoint robot operation is under arithmetic control, multiplication and division calculators and a trigonometric function table are required because of the need for high-speed arithmetic processing. Recently, a multi CPU system has been widely adopted. An analog circuit conventionally incorporated in the servo of each shaft of the robot is gradually being replaced by the PWM (pulse width method), indicating an ever consolidating trend in favor of soft servos.

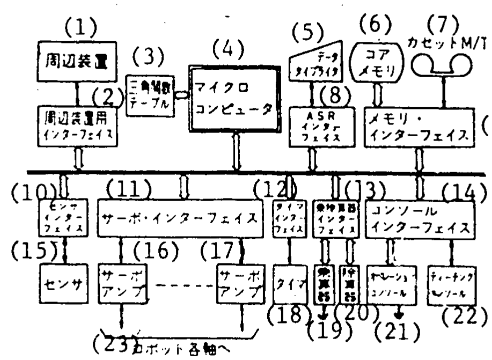


Figure 4. Robot Control Unit Arrangement

Key:
(1) peripherals
(2) peripheral interface
(3) trigonometric function table
(4) microcomputer
(5) data typewriter
(6) core memory
(7) cassette M/T
(8) ASR interface
(9) memory interface
(10) sensor interface
(11) servo interface
(12) timer interface
(13) multiplication division calculator interface
(14) console interface
(15) sensor
(16) servo amp
(17) servo amp
(18) timer
(19) multiplication calculator
(20) division calculator
(21) operation console
(22) teaching console
(23) to each shaft of robot

Principal Function

The following four items are considered the principal functions of the intelligent robot, and mechanical sophistication and intellectual development of the robot are achieved by upgrading and combining functions.

1. Rectangular Coordinate System Guidance (see Figure 5)

Guidance of robots by rectangular coordinate action directives are easy for man to comprehend; an act (wrist correction) that only changes the direction (posture) of the hand without changing the target point of the robot's hand is an essential function for the free and unrestricted operation of the robot.

In order to determine the position of the robot, it is necessary to transform the coordinates from the robot coordinate system to a rectangular coordinate system. Likewise, as described previously, when the robot is driven by a rectangular coordinate system action directive from man, it is necessary to transform inversely from the rectangular coordinate system to the robot coordinate system.

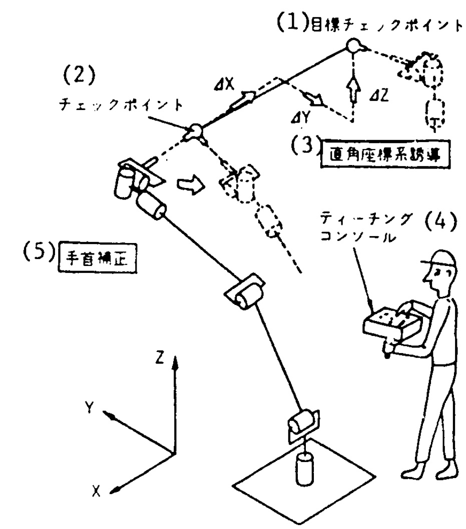


Figure 5. Operation of Robot Under Discussion

Key:
(1) target check point
(2) checkpoint
(3) rectangular coordinate guidance
(4) teaching console
(5) wrist correction

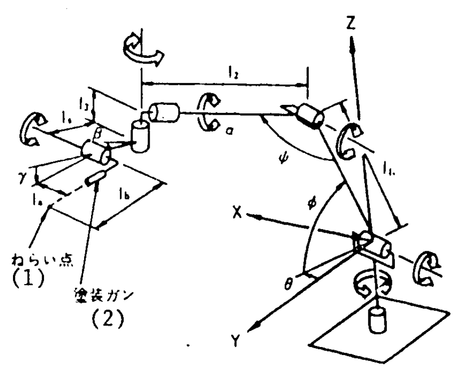


Figure 6. Coordinate System and Dimensions of Painting Robot

Key: (1) target point (2) painting gun

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In the case of the painting robot shown in Figure 6, transformation from the robot coordinate system to the rectangular coordinate system is accomplished by Equation (1).

$$\begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(-\phi) & \sin(-\phi) & l_1 \\ 0 & -\sin(-\phi) & \cos(-\phi) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$
$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\pi-\phi) & \sin(\pi-\phi) & l_2 \\ 0 & -\sin(\pi-\phi) & \cos(\pi-\psi) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\alpha & 0 & \sin\alpha & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\alpha & 0 & \cos\alpha & -l_3 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$
$$\begin{pmatrix} \cos\beta & \sin\beta & 0 & l_4 \\ -\sin\beta & \cos\beta & 0 & l_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(-\gamma) & \sin(-\gamma) & 0 \\ 0 & -\sin(-\gamma) & \cos(-\gamma) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ l_5 \\ 0 \\ 1 \end{pmatrix} \quad (1)$$

However, increases of each shaft of the robot, $\Delta\theta$, $\Delta\phi$ and $\Delta\delta$ to drive the robot to the extent of the increases of X, Y and Z axial directions, ΔX, ΔY and ΔZ in the rectangular coordinate system are obtained from Equation (2).

$$\left.\begin{array}{ll} \begin{pmatrix} \Delta\theta \\ \Delta\phi \\ \Delta\delta \end{pmatrix} = \begin{pmatrix} \frac{\partial X}{\partial\theta} & \frac{\partial X}{\partial\phi} & \frac{\partial X}{\partial\delta} \\ \frac{\partial Y}{\partial\theta} & \frac{\partial Y}{\partial\phi} & \frac{\partial Y}{\partial\delta} \\ \frac{\partial Z}{\partial\theta} & \frac{\partial Z}{\partial\phi} & \frac{\partial Z}{\partial\delta} \end{pmatrix}^{-1} \begin{pmatrix} \Delta X - K_X \pm V_C \\ \Delta Y - K_Y \\ \Delta Z - K_Z \end{pmatrix} & \text{(i)} \\ \Delta\beta = \frac{\beta_{i+1} - \beta_i}{N}, \quad \Delta\gamma = \frac{\gamma_{i+1} - \gamma_i}{N} & \text{(ii)} \\ K_X = \frac{\partial X}{\partial\beta}\Delta\beta + \frac{\partial X}{\partial\gamma}\Delta\gamma, \quad K_Y = \frac{\partial Y}{\partial\beta}\Delta\beta + \frac{\partial Y}{\partial\gamma}\Delta\gamma, \quad K_Z = \frac{\partial Z}{\partial\beta}\Delta\beta + \frac{\partial Z}{\partial\gamma}\Delta\gamma & \text{(iii)} \\ \delta = \phi + \psi & \text{(iv)} \end{array}\right\} (2)$$

K_X, K_Y and K_Z are for correcting the angle of the wrist so that the target point of the hand will not shift when it is turned by $\Delta\beta$ and $\Delta\tau$, and V_c is given so that the robot can follow the X axial movement at a speed of V_c.

The painting robot in Figure 6 has a complex coordinate arrangement. Multiple solutions are obtained when Equation (1) is inversely transformed, which requires a long process time for assessment of the solutions. In that case, the speed directive system such as Equation (2) is adopted, but usually Equation (1) is inversely transformed as long as the robot coordinates are simple.

2. Interpolation

When given the positions at two checkpoints and the posture of the robot's wrist, the target point of the hand is guided to the next checkpoint linearly at a designated speed while the wrist posture is being changed at the same speed. This is called line interpolation.

For this, each shaft of the robot is driven according to each microtransfer distance after obtaining microtransfer quantum $\Delta L = V/\Delta T$ in one sampling time from sampling time ΔT and speed V and dividing the distance L between the two points by ΔL into N number of equal portions. However, arithmetic and driving methods for the interpolation will be the same as in the guidance in the preceding section.

3. Search for Checkpoints

Checkpoints at each specific location on variously shaped elements can be searched if a near distance sensor is attached to the robot's hand as shown in Figure 7 and paired with the actions shown. For instance, when the steel plates orthogonally meet, as in item (a) of Figure 7, the position of the horizontal steel plate will be detected by the vertical sensor, and subsequently the position of the vertical steel plate will be detected by the horizontal sensor, to obtain the location of the checkpoint on the line of intersection of the steel plates. In the same illustration, examples of search are shown. The checkpoint search potential range is further expanded, of course, when search actions are improvised in accordance with the shape of an element, when the shape is known.

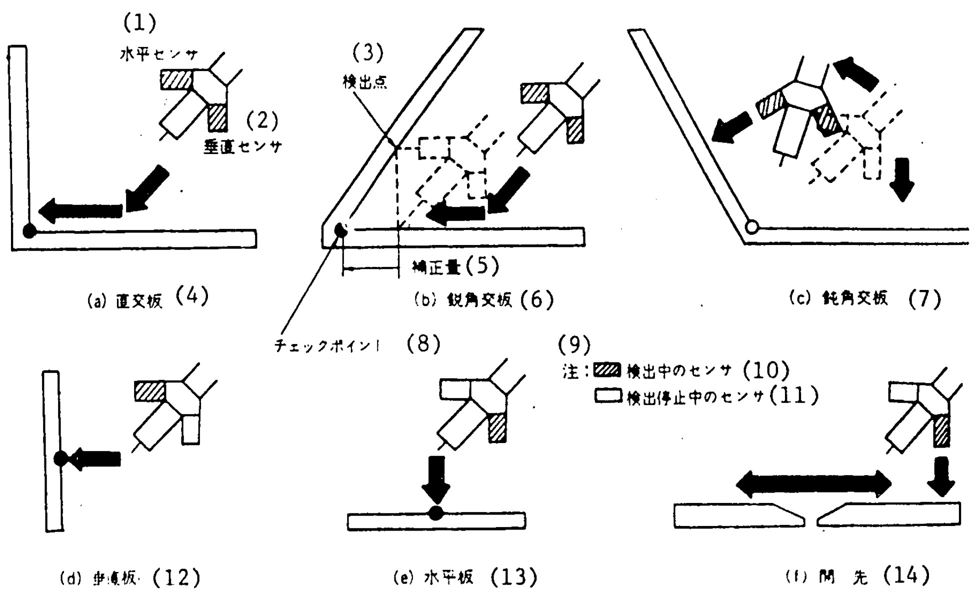

Figure 7. Various Examples of Work Checkpoint Search Method by Near Distance Sensors

Key:

(1)	horizontal sensor	(8)	checkpoint
(2)	vertical sensor	(9)	checkpoint
(3)	detection point	(10)	sensor on
(4)	orthogonal plates	(11)	sensor off
(5)	compensation	(12)	vertical plate
(6)	acute angled plates	(13)	horizontal plate
(7)	obtuse angled plates	(14)	open root

4. Computation of Checkpoint

As in Figure 8, a straight line that passes through two checkpoints is determined by those points, and the corner point which is the point of intersection of the two straight lines can be also calculated. Likewise, as shown in item (b) of the illustration, the line of intersection of two cylinders can be obtained when the center position and radius of the main pipe and the branch pipe are given. Checkpoints on the line of intersection can be also calculated.

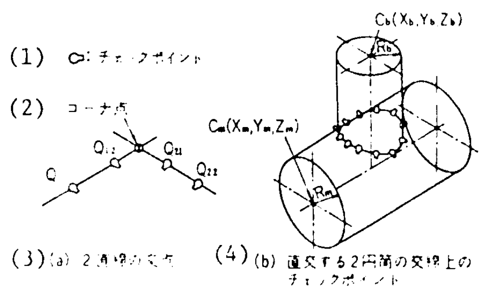

Figure 8. Calculable Checkpoints on the Line of Intersection

Key:
(1) checkpoint
(2) corner point
(3) point of intersection of two straight lines
(4) checkpoints on the line of intersection of two orthogonal cylinders.

Corner points are often located at corners of box welding structures, which raises many problematic points for teaching. If corner points can be obtained by calculation, cumbersome teaching will be unnecessary. Also, if checkpoints on the line of intersection of two cylinders are obtained by calculation, almost unmanned operation is feasible for multilayer welding of complex curves, which require excessive teaching time and labor when conventional playback robots are used.

Program

Functions of intelligent robots as far as essential parts are concerned are all realized by software. Figure 9 gives an outline of the program structure. The progress monitor system (PMS) processes multiple tasks. Naturally, for a high starting priority level, an emergency and abnormal stop processing task is allocated. Also, in allocating the task, full consideration of the processing content is given in order to shorten the total process time. By using software for the control function, it is feasible to give a delicate abnormality handling function and interlock function, which are not available in conventional robots.

As the robot concerned can also perform rationality checks that monitor misteaching and misoperation by the operator, it can greatly contribute to reducing the teaching processes and preventing accidents before they occur.

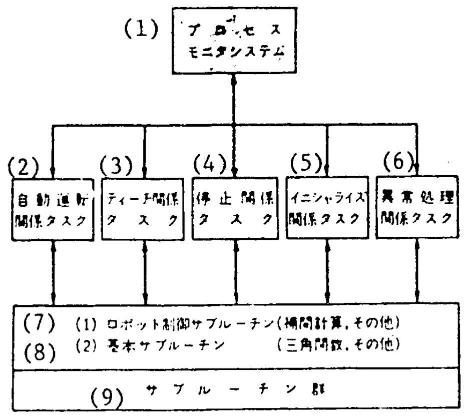

Figure 9. Basic Structure of Programs by Function

Key
(1) process monitor system
(2) automatic running task
(3) teaching task
(4) halt task
(5) initializing task
(6) abnormality handling task
(7) robot control subroutine (interpolation calculation, others)
(8) basic subroutine (trigonometric function, others)
(9) subroutine group

Conclusion

Welding and painting robots have been manufactured as intelligent industrial robots. We have discussed the basic concept of the robots, the principal functions by which they were realized, and the coordinate arrangement of the robot proper, control unit and programs.

Welding and painting robots developed on the basis of this concept are now at work achieving remarkable automation and labor-saving effects. We are determined to make further efforts in the future to improve the robot's intelligence along basic lines.

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Arc-Welding Robot 'Mr Aros'

Tokyo KIKAI SEKKEI in Japanese Vol 25 No 12, Oct 81 pp 69-72

[Article by Shimon Ando and Akira Tsuchihashi, Hitachi Ltd]

[Text] We have made clear that the principal functions and basic concept of intelligent industrial robots explained in the previous article have been effective, using examples of automation cases of almost manless, 200-pass, multilayer welding of saddle nozzles for pressure vessels by robots, which searched welding lines, often calculating the locus by themselves, and welded almost without the assistance of man the center frame of an oil pressure power shovel when several points were taught.

In this paper, we will provide a concrete explanation of the robots by using two applied cases to welding work.

One of these is the virtually manless welding of construction machine parts by robots which have a distance sensor in the hand and which search welding lines by themselves practically without any directives from man. The other is the virtually manless 200-pass multilayer welding of saddle nozzles and cutting of the open roots by gas using robots without a hand sensor but with the ability to calculate the locus by themselves once several points are taught.

Basic Specifications of Welding Robots

The robot used for arc welding the center frame of a power shovel which serves as a construction machine is a standard type and was shown in Figure 2 and Table 1 in the previous article. Figure 1 shows a saddle welding robot which is made by modifying Mr Aros' wrist to make it suitable for saddle nozzle welding. Its standard specifications are listed in Table 1. The wrist, consisting of twist and bend shafts, was installed on the end of a rectangular coordinate arm composed of X, Y and Z shafts. A gas torch will be held in the hand when cutting the open root by gas, while an arc welding torch will be held when welding.

Each shaft of the robot is driven by an electric oil pressure servo, and the position of each shaft is detected by a potentiometer. In Table 2, the specifications of a pulse MIG welder used for saddle welding are listed.

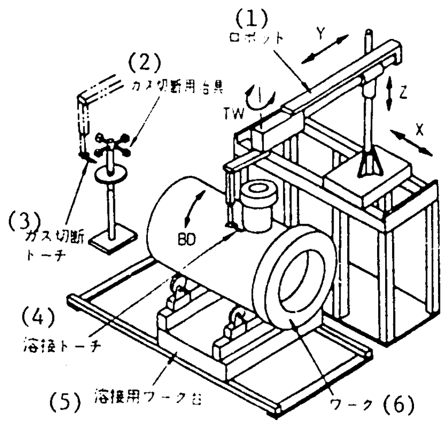


Figure 1. Saddle Welding Robot Arrangement

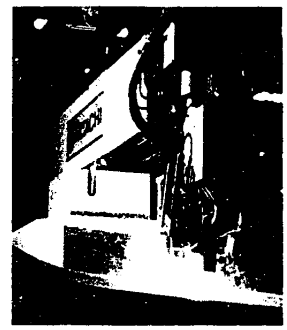


Photo 1. Mr Aros

Key:
(1) robot
(2) metallurgical tool for gas cutting
(3) gas cutting torch
(4) welding torch
(5) welding workbench
(6) work

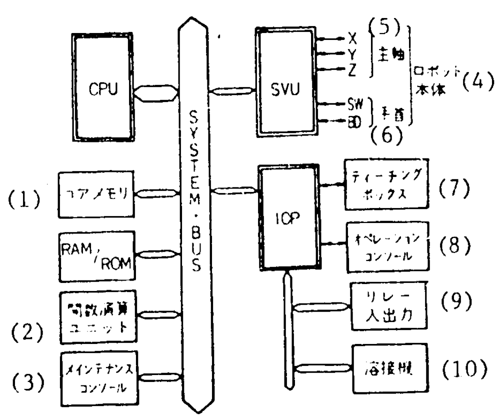
Table 1. Specifications of Saddle Welding Robot

Robot shafts	Stroke	Speed	Driving speed	Control method	Position detection
X	1,000 mm	welding speed at tip of torch	oil pressure	electric oil pressure servo	potentio-meter
Y	800 mm	100~700 mm/min			
Z	800 mm				
twist TW	0~400°	maximum speed 6,000 mm/min	special oscillation motor		
bend BD	45~90°				

Table 2. Specifications of Welder

Welding power source	Style			DR-MPY
	Rated initial voltage			200 V ±10 percent 3P
	Rated initial input			approximately 30 kVA
	Rated frequency			50/60 Hz
	Rate of use			100 percent
	Output	Current	Base	50∼300 A
			Peak	100 A (average)
		Voltage	Base	10∼35 V
			Peak	10 V (average)
	Maximum peak current			100 V (at time of 200 V input)
	Pulse frequency			50/60 Hz, or 100/120 Hz
	Outside dimensions			550(w) x 1,170(h) x 930(d)
Feeding device	Type			TS-55Y
	Rated current			500 A
	Diameter of wire in use			1.2 φ

The control unit is arranged the same as shown in Figure 4 of the preceding article, but recent control units have a multiprocessor arrangement as shown in Figure 2. The robot action control program is processed by a master CPU. Each shaft of the robot receives action directives through an SVU microprocessor. A teaching box, operation console and external machinery and equipment are connected to the master CPU through an IOP microprocessor.



Key:
(1) core memory
(2) function calculation unit
(3) maintenance console
(4) robot proper
(5) main shafts
(6) wrist
(7) teaching box
(8) operation console
(9) relay input and output
(10) welder

Figure 2. Arrangement of Welding Robot Control Unit

Welding of Box Structures

The welding lines of box structures consist almost entirely of straight lines. Furthermore, the welding line is often located at an inside corner of orthogonally intersecting steel plates, which is considered the most favored work for the welding robot. As a typical example of welding robot application, the upper and lower center frames of an oil pressure power shovel are shown in Figure 3.

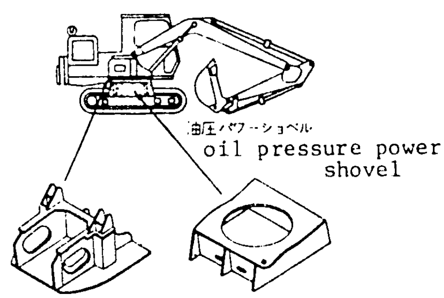


Figure 3. Center Frames of Oil Pressure Power Shovel

For welding work such as this, the work is set on a positioner as shown in Figure 4. The turntable of the positioner can turn and tilt, and thus change the position and posture of the work so that the robot can always perform horizontal fillet welding. The welding is carried out according to the following method.

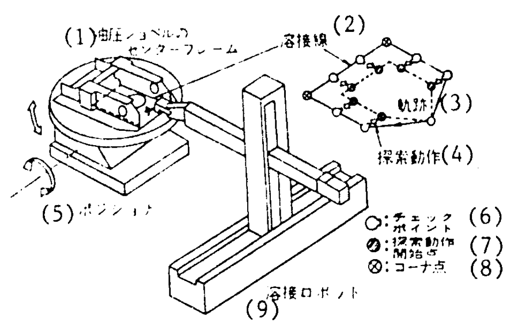


Figure 4. Welding of Center Frame by Welding Robot Mr Aros

Key:

(1) center frame of oil pressure shovel
(2) welding line
(3) locus
(4) search action
(5) positioner
(6) checkpoints
(7) search action starting point
(8) corner point
(9) welding robot

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For example, taking a look at the "コ" shaped welding lines shown in the illustration, first, two checkpoints are roughly taught to robots regarding one straight welding line for standard work. When new work is set on the positioner, pretaught checkpoints are shifted to the safe side and designated as search starting points. After tracing once around the welding lines by passing these points, search action is executed at each search starting point to confirm the position of each checkpoint. Using these checkpoints, straight lines are determined, and corner points where these straight lines intersect are calculated. Eventually, all welding lines are determined, and welding can be performed along these welding lines.

As described above, if checkpoints are roughly taught regarding one piece of work at first, all work that follows can be handled by the robot itself. The working ratio of the welding robot is extremely good; it can operate continuously day and night. Unmanned operation is virtually achieved for the present.

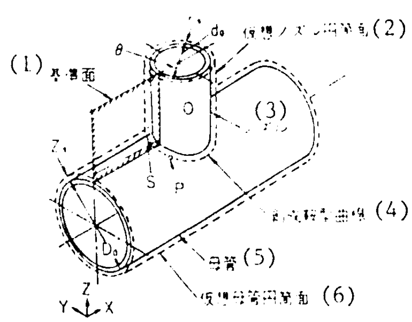
Gas Cutting and Multilayer Welding of the Open Root of Saddle Nozzles

The joint of a main pipe and a branch pipe is called a saddle nozzle. A saddle nozzle has a complex three-dimensional shape. Also, a saddle nozzle of a nuclear-related pressure vessel in particular requires high quality multilayer welding with up to 200 passes because of the large amount of stress involved. This work has been considered too difficult to be automated by conventional playback type industrial robots.

However, the action capabilities of this robot were successfully turned to an algorithm by adopting a special open root form that maintained a constant welding height, after the following two points were brought to attention: 1) the locus of a saddle nozzle can be easily obtained by calculation of the line of intersection of two cylinders, a main pipe and a branch pipe; 2) with one-pass welding, thickness (height) is almost invariable, even when the welding site is tilted. When the minimum checkpoints necessary for calculation are taught, the rest of the welding task can be handled by the robot itself.

1. Saddle Locus Control Program

The saddle locus can be obtained by numerical equation as a line of intersection of a main pipe and a branch pipe as shown in Figure 5. The locus of the branch pipe is divided into 64 equal parts as checkpoints, and the robot is transferred between the checkpoints by line interpolation.



Key:
(1) standard surface
(2) imaginary nozzle cylinder surface
(3) nozzle
(4) generated saddle curve
(5) main pipe
(6) imaginary main pipe cylinder surface

Figure 5. Saddle Locus Generation Method

The locus of subsequent passes in multilayer welding is calculated using the radius of the main pipe and the branch pipe increased by ΔZ and ΔR.

2. Torch Angle Control Program

The torch angle in the direction of the branch pipe's radius always faces toward the center of the branch pipe, but the angle of elevation relative to the main pipe must be changed to face the direction suitable for the welding operation, as shown in Figure 6. In order to simplify the algorithms through basic welding experiments, the angle relative to the surface of the main pipe is designated in this case to a fixed ψ_0 so that the torch angle of elevation will be expressed by a simple numerical equation.

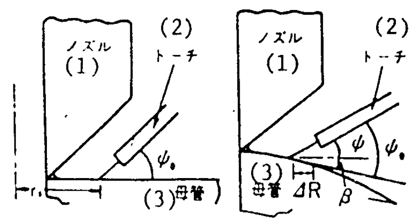
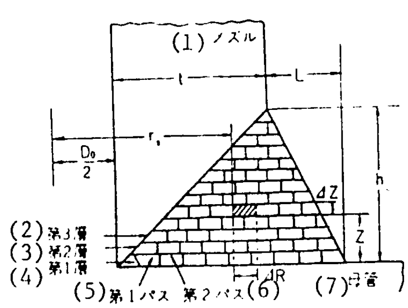


Figure 6. Torch Angle Control Method

Key: (1) nozzle
(2) torch
(3) main pipe

3. Lamination Control Program by Automatic Allotment of Open Root

The amount of lamination and form of the bead for one-pass welding can be determined by welding conditions such as current, voltage and speed. Therefore, the number of welding layers and the number of passes for each layer can be automatically computed when the form of the open root is given. Figure 7 shows an automatic allotment based upon the amount of deposit per pass (height ΔZ, width ΔR) in the open root section on the standard surface θ=0. The welding on each pass is applied by the saddle locus control based upon the automatically allotted individual pass.



Key:
(1) nozzle
(2) third layer
(3) second layer
(4) first layer
(5) first pass
(6) second pass
(7) main pipe

Figure 7. Automatic Allotment of Open Root

4. Welding Speed Control Program

Although the height of the open root is always maintained at a fixed level, the sectional area of the open root varies according to the positions on the locus, and the amount of weld increases at the widest part of the open root. The amount of the change is $1/\cos\beta$ as shown in Figure 8, and the amount of weld is controlled by changing the welding speed for this part.

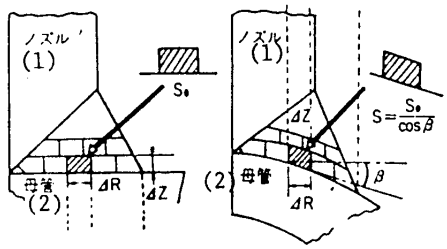


Figure 8. Welding Speed Control Method

Key: (1) nozzle (2) main pipe

5. Welding Direction and Starting Point Control Program

The welding direction was reversed on each pass in consideration of the robot mechanism and cable handling. Also, the welding starting point was shifted in a zigzag, as shown in Figure 9, for each pass and each layer lest the strength of the weld be jeopardized if the welding starting points were concentrated in one location. This was accomplished by an appropriate shifting of checkpoints with which to start welding, since the saddle locus of one pass is approximated by a polygonal line that connects 64 checkpoints.

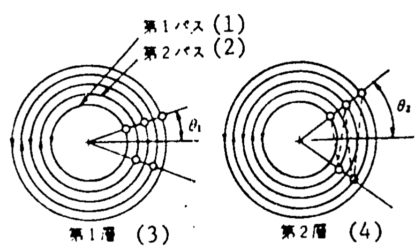


Figure 9. Welding Direction and Starting Point Control Method

Key: (1) first pass (2) second pass (3) pass layer (4) second layer

6. Open Root Gas Cutting Control Program

Since a numerical equation that expresses the form of the open root is used for the automatic allotment of the open root, the target position and posture of the gas cutting torch are controlled using this equation to conduct gas cutting.

Once the robot is taught about several checkpoints that indicate the relative positions of the branch pipe and the main pipe and checkpoints that designate the open root form, it can do the job of welding up to 200 passes virtually without assistance from man.

Incidentally, when the robot operation was in its initial stage, a welder was assigned to the robot to help clean the clogged opening of the welding torch, to observe welding conditions and to correct a few welding conditions. In proportion to the welding work mastered by the robot, the human share was greatly reduced and the welding quality jumped up.

Conclusion

Industrial robots are believed to have a promising future as a very flexible general machine which can handle various tasks independently without human instruction for everything, once it is given mental faculties. Judging by the present technological level, however, a high level of intelligence cannot be expected from robots. Evidently, to begin with we must realize industrial intelligent robots by means of efficient utilization of the computer's arithmetic processing ability, simplification of the work content and the proper combination of the intelligent robot's basic functions.

We have introduced center frame welding work, which achieves manless welding by providing a saddle nozzle multilayer welding function and a simple search function using an arithmetic processing ability. All of these robots are operating without failure, and are demonstrating remarkable automation and labor-saving effects. It is considered very important to improve the intelligence of robots by selecting and polishing the work contents considered intelligent for robots from among the various tasks given to industrial robots.

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Assembly Robot 'Nebot'

Tokyo KIKAI SEKKEI in Japanese Vol 25 No 12, Oct 81 pp 73-76

[Article by Noboru Morota*, Nippon Electric Company]

[Text] In recent years, when user needs have become increasingly diversified, the robot has risen swiftly to the spotlight as a very flexible piece of production equipment that can quickly meet product model changes and accommodate multiproduct small quantity production. Assembly work, especially automation of multiproduct small quantity production, in the manufacturing industry has been considered a difficult field and has often depended upon human labor. However, a new field is about to be pioneered as a result of development and practical application of assembly robots. It appears that in the near future it will no longer be a dream to realize a FMS robot as shown in Figure 1.

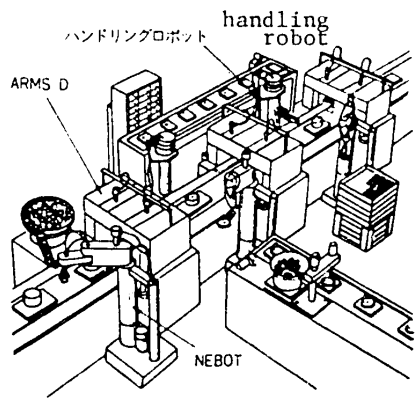

Figure 1. FMS Pairing a Robot Developed by NEC and a Conveyor

Regarding a requirement for assembly robots to be able to contribute on the production line, "they should have functions which can easily substitute for current work by human labor." For this, the following conditions must be met:

1. Due to the characteristics of the robot, one robot cannot be expected to save a great deal of labor. The price of the robot therefore must be encouraging enough for it to be introduced.

2. The area occupied by a robot must be equivalent to that occupied by a man.

3. The working speed of a robot must be comparable to that of a man.

4. The position determination must be highly accurate.

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5. The flexibility and operability must be excellent.

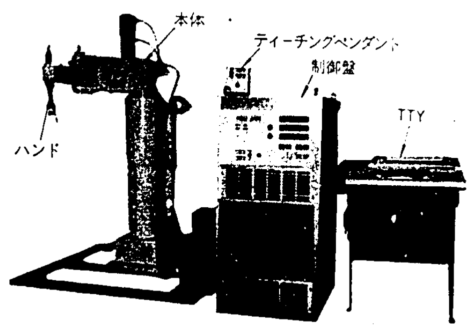
Based upon these ideas for development, a joint type industrial robot, "Nebot," which is modeled after the human body form, was developed and put into practical application incorporating an NEC microcomputer and NC technology. Photo 1 shows the external appearance of this robot. In structure, it belongs to the same system as the Model Scara robot developed and put into practice by Prof Makino of Yamanashi University. However, our robot can determine positions in three-dimensional space due to an arm that turns and moves up and down through the control of a servo motor.

teaching pendant

robot proper

control panel

hand



Characteristics of "Nebot"

As the movements of the robot resemble those of a human, it can be utilized for a broad range of uses from various assembly tasks to carrying jobs. The main characteristics are:

1. Because the arm of the robot is a copy of a human arm, it is comparatively easy to automate conventional human work by the robot.

2. Because it is a joint type, the action range is large compared to the area occupied by the robot.

3. All three shafts are driven by DC servo motors. The robot can determine positions speedily and accurately.

4. The robot has many good points for assembly work.

a. It is good at vertical insertion (because up and down movements are operated by a direct acting system).

b. Because it has a work direction correction function, the direction of the work will not deviate even after a turn.

c. The vertical directional insertion force is large.

d. Because of compliance of the arm, fit insertion is simple.

e. Because it has teaching, X-Y axial inputting and condition diverging functions, speed and acceleration and deceleration times can be set freely in accordance with the values suitable to the application by using parameters.

f. Because it is equipped with a rich self-diagnostic function, operability of the robot is great and use of the robot can be mastered without difficulty by anyone.

Structure of Robot Proper

The external appearance of Nebot proper is shown in Figure 2. There are three models--large, medium and small. The carrying capacity is 5 kg in the medium size. The arm length is 800 mm and the height of the hand portion is 850 mm, high enough to handle work on a standard workbench. At each joint of the arm, a high precision decelerator harmonic drive is built in. The up and down motion mechanism is comprised of a ball and three shafts. Under the joint, there is a work direction correction mechanism that utilizes wirerope and a timing belt. The main specifications of the robot proper are shown in Table 1.

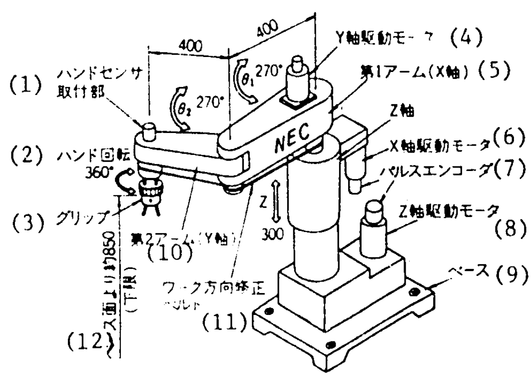
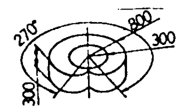


Figure 2. External Appearance of Nebot

Key:
(1) hand sensor attaching site
(2) hand turn
(3) grip
(4) Y shaft driving motor
(5) first arm (X shaft)
(6) X shaft driving motor
(7) pulse encoder
(8) Z shaft driving motor
(9) base
(10) second arm (Y shaft)
(11) work direction correction belt
(12) approximaely 850 mm from the base surface (lower limit)

Table 1. Main Nebot Specifications (medium size)

Structure		Joint model	
Degree of freedom		3 (5 options)	
Action range			
Maximum speed	First arm	120°/sec	biaxial composition
	Second arm	120°/sec	1200 mm/sec
	Up and down movements	260 mm/sec	
Carrying weight		5 kg max	
Position reproduction accuracy		±0.05	

Robot Hand Structure

The hand structure of Nebot with an analog sensor is shown in Figure 3. When moving up and down during assembly work, tightness of the fit can be judged by sensing the applied pressure with a potentiometer. Also, there is an emergency stop function that prevents the destruction of the arm when the tip of the hand hits an obstacle during its downward movement. In some robots, a microswitch or a photosensor is used in place of an analog sensor.

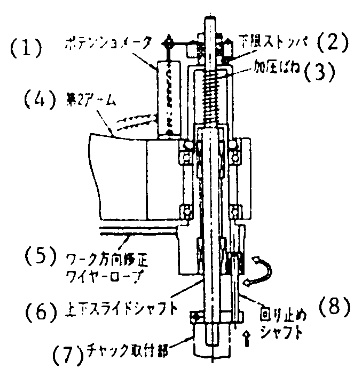


Figure 3. Robot Hand Structure

Key:
(1) potentiometer
(2) lower limit stopper
(3) pressure spring
(4) second arm
(5) work direction correction wirerope
(6) up and down slide shaft
(7) chuck fitting site
(8) turn stop shart

Control Unit

The composition of the hardware of the control unit is shown in Figure 4. Except for the terminals, the teaching pendant and motor are built into the main body of the control. The terminal is for editing application programs using keyboards.

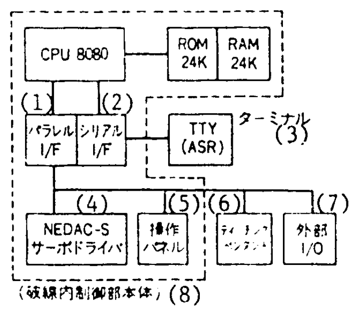


Figure 4. Hardware Arrangement

Key:
(1) parallel
(2) serial
(3) terminal
(4) servo driver
(5) operation panel
(6) teaching pendant
(7) exterior I/O
(8) items within the broken line are contained in the main body

Additionally, the teaching pendant, which is also used for loading and saving of application programs using paper tapes, serves the purpose of giving action directives to each shaft during teaching. It is separate from the main body, since it performs its duty while overseeing tooling near at hand.

The main body of the control has built-in CPU 8080, ROM, RAM and a servo driver. An operation panel is installed in front of the main body.

Software

The robot language Pasla, developed by NEC, is used for Nebot. Pasla is a general term for the software system that includes the Nebot control command, file management program and operating system for system management. The arrangement of software is shown in Figure 5.

Users prepare application programs through a conversation system using keyboards with the assistance of a complete file maintenance module. Application programs are composed using commands from the command table, as shown in Table 2, and registered in the file. A maximum of 255 files can be registered in the file. Similarly, a maximum 255 command lines can be designated in one file. The sentence number must be designated for each command. Besides these features, general memories open to users are available. General memories are of the one byte unit, and can be used up to a maximum of 255 memories.

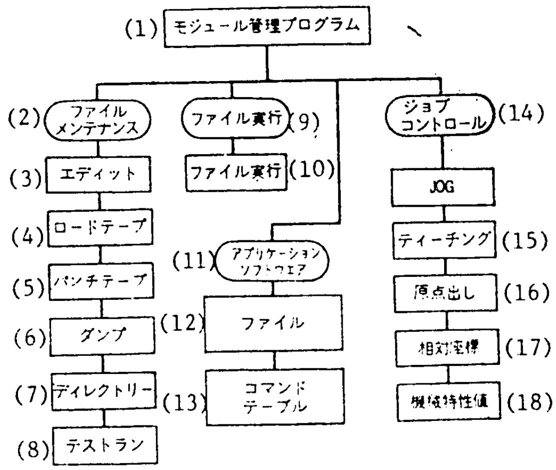


Figure 5. Software Arrangement

Key:
(1) module management program
(2) file maintenance
(3) edit
(4) load tape
(5) punch tape
(6) dump
(7) directory
(8) test run
(9) filing
(10) filing
(11) application software
(12) file
(13) command table
(14) work control
(15) teaching
(16) origin access
(17) relative coordinates
(18) mechanical characteristic values

Table 2. Command Table

	Command Table
XY, MZ	action directive to arm
ON, OF	control of external machinery and equipment (bit unit)
DL	timer (10 ms∼2.5 sec)
JP, JZ, JN, JE, JG JL, BZ, BN	branch instruction ● unconditional branch ● branch by general memory ● branch by external input
CF, RE	subfilecone return
NT	message print
DF, IC, DC	general memory operation instruction
MB	general memory

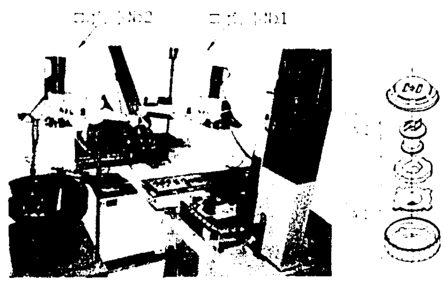
general memory 255 (byte)

Nebot Application Examples

As discussed previously, Nebot has various characteristics and is used in many ways. However, in the following, practical examples realized by our company will be described.

Photo 2 is an example of automation of an assembly process by robots. This automatic assembler links two robots, assembles five different parts by harmonious motions, and sets the work on the existing machine in the next process. All the work has directional orientation.

robot No 2 robot No 1



robot No 2

robot No 1

Photo 2. Automatic Assembler With Two Linked Nebots and Work

Photo 3 shows the automatic assembly of the keyboard switch, which is an example of the automation of simple repetitious work by robots. The name has a built-in high-resolution sensor to judge the quality of the fit.

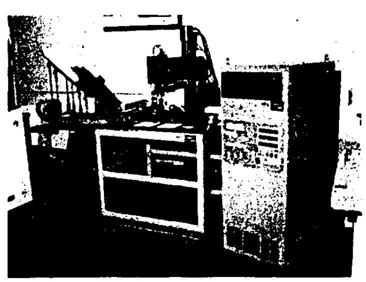


Photo 3. Assembly Robot for Keyboard Switch

Figure 6 gives an example of an automated inspection process by a robot. Conventionally, products A and B were inspected by a worker. The man was replaced by a robot for manless operation after the floor layout was changed. The assembler sets products brought by a belt conveyer on the inspection head and lines up the inspected products in sequence on trays for rejected and accepted products. A robot handles the same work as a man.

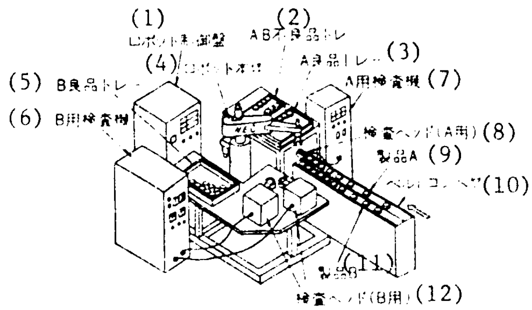


Figure 6. Unmanning of Inspection Process by Robot

Key:

(1) robot control panel
(2) tray for rejected A and B
(3) tray for accepted A
(4) robot proper
(5) tray for accepted B
(6) inspection machine for B
(7) inspection machine for A
(8) inspection head (for A)
(9) product A
(10) belt conveyer
(11) product B
(12) inspection head (for B)

Photo 4 is an actual example of assembling IC and LSI print substrates. IC and LSI are of the double hand automatic switch type. This type of robot can handle assembly work on a belt conveyer. It appears that the demand for assembly of special parts on print substrates will be strong in the future.

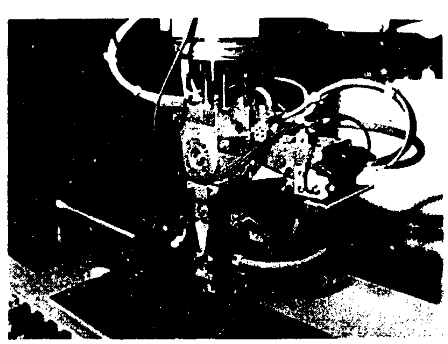


Photo 4. IC and LSI Assembly by Robot

Another practical use of Nebot is seen in transferring TV Braun tubes on a continuously operated hanger conveyer. Also, work is underway for the practical application of screw-tightening of 6 mm hexagonal bolts, which requires a high technology that balances and tightens the bolt using six screws in three stages by torque. However, this work is being successfully managed by skilifully using the up and down motions of the robot.

Conclusion

Under the present condition, when robots are to be used for assembly tasks, the cost of designing the work supply part application, for instance, is higher than the cost of the robot itself. One of the future assignments is the grouping of applications into a unit by components so that applications can be designed by pairing of units. Furthermore, we would like to contribute to the advancement of industries through our efforts to expand further the range of the work object by developing highly efficient, inexpensive visual and tactile sensors for the enhancement of robot intelligence.

Literature for Reference

Hiroshi Makino, "Scara Robotto No Kaihatsu (Development of Scara Robot)," Material for Spring Convention of the Precision Machinery Society, 1981

Painting Robot 'Kobelco-Trallfa'

Tokyo KIKAI SEKKI in Japanese Vol 25 No 12, Oct 81 pp 77-80

[Article by Akio Hirose*, Kobe Steel, Ltd]

[Text] The introduction of robots in the painting industry is increasing in order to save labor, increase productivity, and to improve the work environment and the product quality. The first Trallfa robot was completed in 1969. This robot, which currently claims 80 percent of the world's market share, is structured with five or six oil pressure actuators controlled by a microcomputer, and moves smoothly at a high sampling efficiency. A flexiarm that has the same function as the human wrist is also produced (see Photo 1). In addition, various magnification functions are furnished by means of utilizing a microcomputer.

Summary of Robot

1. Automation in Painting Field

The call for automation is strong in the painting industry, which must deal with a shortage of painting workers associated with work in adverse environment, inflation of personnel expenses, and generation of inferior painted goods. Furthermore, the introduction of painting robots is rapidly rising at present, when the

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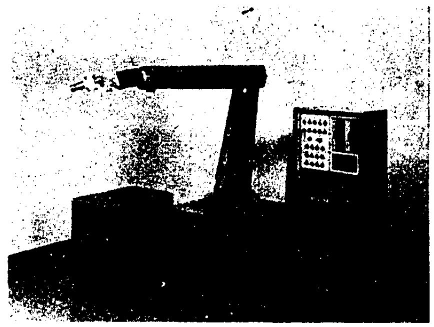

Photo 1. External Appearance of Flexiarm Robot

production mode is shifting from mass production of a few items to moderate production of numerous items. As motivations for introducing painting robots, labor-saving, increase in productivity, improvement of work environment, improvement of product quality and energy conservation are cited. Regarding the introduction of a robot, superficial or near-sighted arguments about the replacement of men by robots are meaningless. However, once the functions of the robot are understood and the robot is organically utilized, productivity and product quality will be stabilized and improved, and labor-saving will be effectively achieved, eventually freeing man from working in an adverse environment.

2. History and Design Idea

Spray painting work entails artistic elements and is different from transporting, assembling and spot welding tasks. Actions continue in time and space. Static handling does not exactly suit work. Life itself is continuous movement. Trallfa of Norway understood these points correctly, and completed a painting robot in 1969 based on the idea of reconstructing a human skill precisely in a machine, and has repeatedly remodeled it to date. This basic technology consists of a joint manipulator which is a mechanism generically called a Trallfa model, a continuous pass control (CP control) which is the control mechanism, and electric oil pressure servos for driving.

Since its debut, the Trallfa robot has become well established as a painting robot characterized by a refined graceful figure and smooth motion; it claims over 1,000 robots working in the world and 80 percent of the market share.

Our company entered into a technical tie-up with Trallfa in 1973, and was the first to introduce these Trallfa painting robots into Japan. For 7 years since that time we have added our own technology, improved the original, and produced and sold it as the Kobelco Trallfa robot to arrive at the current mass popularization stage.

Basic Structure

The Kobelco-Trallfa robot consists of three parts--a manipulator, a control panel and an oil pressure unit.

1. Manipulator (see Figure 1)

The standard manipulator consists of fixation columns, a base, a vertical arm, a horizontal arm and a wrist, and is controlled by an oil pressure actuator with electric-oil pressure servo valves called servos 1,2,3,4 and 5. Servos 1,2 and 3 are a linear actuator which actuates the turning to and fro and up and down motions of the arm respectively. Servos 4 and 5 are rotor actuators which turn the spray gun vertically and horizontally; servo 5 is fixed to the output shaft of servo 4.

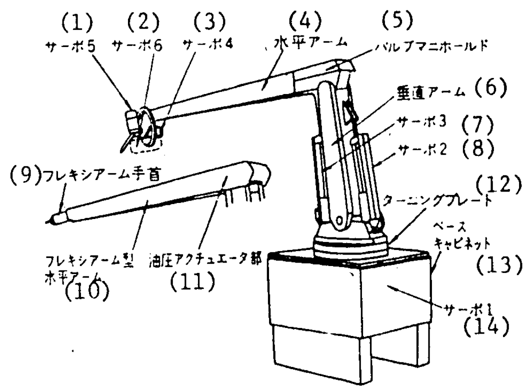

Figure 1. Structure of Manipulator and Names of Each Part

Key:

(1)	servo 5	(8)	servo 2
(2)	servo 6	(9)	flexiarm
(3)	servo 4	(10)	flexiarm type horizontal arm
(4)	horizontal arm	(11)	oil pressure actuator
(5)	valve manifold	(12)	turning plate
(6)	vertical arm	(13)	base cabinet
(7)	servo 3	(14)	servo 1

There is a flexiarm manipulator as well as a standard manipulator. This gives the robot six degrees of freedom with a twist of wrist added, the same mechanism as a man's wrist. The horizontal arm and wrist of this type are different from the standard type. Servos 4 and 5 become linear actuators that move the wrist up and down and left to right, and Servo 6 becomes a rotary actuator which allows a twisting motion of the wrist. Each actuator has a changeover valve that changes the oil pressure circuit during teaching and makes it possible to provide teaching using little power together with the special accumulator. Likewise each actuator is fitted with a potentiometer and a resolver, and displacement during teaching and reproduction is converted to an electric si al and transmitted to the control panel. Accuracy is improved by installing two sensors.

Each arm is fitted with a balance spring, which means each arm can rest at a desired position when the oil pressure is switched off. Also, each ring of the manipulator maintains high accuracy as it is provided with a design that prevents excessive play.

2. Control Panel (CRC Control Panel)

The electronic control system of this robot is shown in Figure 2.

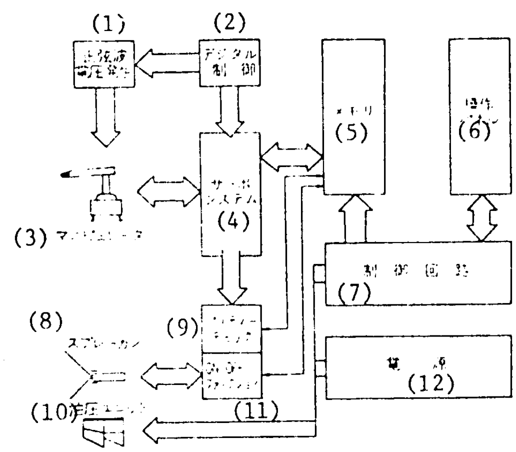

Figure 2. CRC Electronic Control System

Key:

(1)	generation of sine wave voltage	(7)	control circuit
(2)	digital control	(8)	spray gun
(3)	manipulator	(9)	parity check
(4)	servo system	(10)	oil pressure unit
(5)	memory	(11)	ON/OFF function
(6)	console panel	(12)	power source

The position of each actuator is measured every 1/80-1/5 second (switchable) by the servo system during teaching, and the measured values are converted from analog to digital as a mode suitable for recording, and transferred to and stored in the memory. During reproduction, information read into the memory is transferred to the servo system at a rate of 80-5 points/second and compared with the measured values of each actuator at a rate of 80 points/second so as to apply voltage comparable to the difference to each servo valve. At this time, if the information recorded is less than 80 points/second, 80 points/second information can be obtained by interpolating between the points (for example, when information is recorded at 20 points/second, 3 points are interpolated at each space between two points). A microcomputer is used for data processing, including data transfer, comparison and interpolation. Floppy disks are used for the memory, since they have greater recording capacity and require simpler handling than IC memory or wire memory, which makes it possible to have a longer recording time and to record more programs (see Table 1). As described above, this robot is controlled stably by the unprecedented high density position information (80 points/second) and can move speedily and smoothly.

Table 1. Memory Capacity

	Sampling efficiency	Program reproduction time: single disk (minutes)	Program reproduction time: double disk (minutes)	Use
C P	80 seconds	4	8	extremely rapid motions
	40 "	8	16	all kinds of painting
	20 "	16	32	general painting
	10 "	32	64	motions that do not require high speed
	5 "	64	128	very slow motions
P T P	31 P	128	256	
	63 P	256	512	
	127 P	512	1,024	

Specifications

The main specifications are given in Table 2. The standard model has 2 degrees of freedom in the wrist, up and down and left and right. An ON/OFF twist mechanism can be installed, to add a degree of freedom in twisting. Also, the standard model can be converted to a flexiarm manipulator simply by replacing the horizontal arm. Photo 1 previously shown indicates the external appearance of the flexiarm, and Figure 3 indicates the action range.

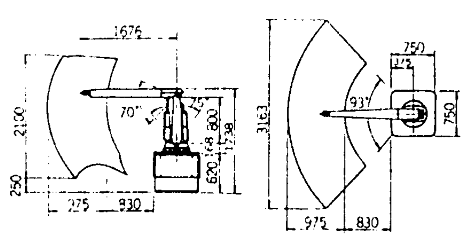

Figure 3. Action Range of Flexiarm Type Robot

Table 2. Main Specifications

			Standard manipulator	Flexiarm
robot proper	degree of freedom	1. arm turn	93° (3,126mm)	93° (3,163mm)
		2. arm to and fro	75° (975mm)	
		3. arm up and down	72° (2,095mm)	72° (2,100mm)
		4. wrist up and down	210°	176°
		5. wrist horizontal	210°	176°
		6. wrist rotation	90° ON/OFF control (option)	210°
	speed		maximum 1.7 m/s	
	rated carrying weight		5 kg	
	repeating accuracy		±1 mm	
	reproducing accuracy		±2 mm	
	oil pressure		70 kg f/cm^2	
	floor area for installation		750 x 750 mm	
	weight		robot proper 500 kg, oil pressure unit 200 kg, control panel 135 kg	
control unit	memory system		CRC system	
	memory capacity		4~128 min	
	maximum program number		64 programs	
	reproduction speed change function		0~120 percent (double speed editing available)	
	external synchronous signal		three circuits each for transmission and reception	
	control system		CP control by electric oil pressure servos	
	power source		AC 200 V 3 phases 50 Hz 7 kVA AC 220 V 3 phases 60 Hz 7 kVA	

1. Flexiarm

Specifications are virtually the same as the standard model. The specifications of the wrist of the flexiarm are shown in Figure 4. The following are accountable characteristics of the flexiarm.

a. It has lighter operation than the conventional wrist.

b. It resembles a man's wrist. Its movement is easily understood and taught.

c. Because of the slim wrist, the arm can enter into narrow spaces.

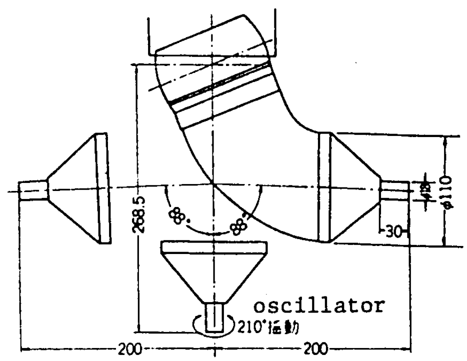

Figure 4. Specifications of Flexiarm Wrist

d. Since oil pressure hose and wiring are not around the wrist, the arm is highly reliable, being free of broken wires and oil leaks.

2. Detailed Specifications of CRC Control Panel

Detailed specifications of the CRC control system are shown in Table 3.

Table 3. Detailed Specifications of CRC Electronic Control System

Data memory/processing	microcomputer + flexible magnetic disk
Manipulator control	five or six degrees of freedom, electric-oil pressure servo position control
Function control	recordable up to 5 ON-OFF signals, 3 output amps are equipped as standard (guiding, loading and driving by DC 24 V, 1A)
Teaching system	CP teaching, variable sampling efficiency (recordable at a rate of 80,40,20 and 10 points/second)
Maximum memory capacity	8-128 minutes (CP), 38,000 points (PTP)
Maximum program number	64
Program search time	below 1 second
Program speed	0-120 percent adjustable by continuous variable dial
Conveyer synchronization	0-120 percent synchronizable to the standard speed by external signals
Automatic program selection	possible by external signals
Automatic repetition and reproduction	"
Start delay	delayable 1-10 seconds by continuous variable dial
Disk monitor	10 abnormality displays by LED, disk number displayable
Program number display	2-line 7-segment LED

(1) Teaching System

The CRC control panel can be either a CP system or a PTP system, and the two can be used separately to suit the purpose by means of a changeover switch.

a. CP Teaching (continuous pass): When a robot is moved continuously, it automatically memorizes the points in the path every 1/80-1/5 second.

b. PTP Teaching (point-to-point): Points in the path of the robot's movement are stored in the memory point by point.

(2) Program Editing

Two disk units are standard equipment for expansion of the memory capacity, for one thing, and also for copying, erasing and editing programs (for example, programs recorded on separate disks can be compiled on one disk. Also, as a variation in editing, double speed editing is possible.)

(3) Data Correction Device (option)

Utilizing two floppy disks, this device partially corrects teaching contents point by point by remote control.

Actual Application

Application examples are selected from among the delivered robots and are shown in Table 4.

Conclusion

Although omitted due to space limitation, there are many options available besides the standard specifications, for instance, movable trucks and a 90° ON-OFF twist mechanism of the gun.

As previously described, a painting robot's life consists of continuous smooth motions, and the balance of the three parts--the manipulator, the oil pressure system and the control system--is extremely important.

Kobe Steel has continuously strived for development and improvement of robots on the basis of abundant achievements by repeated computer simulations and experiments. In the future, we will direct our efforts further to improve the functions, reduce the cost and expand the service system, and we are resolved to devote ourselves to develop new technologies to meet new needs for robots.

Table 4. Applicational Examples of Painting Robot Kobelco-Trallfa (as of March 1980).

Industries delivered to	Use	Gun in use
Automobile industry	body detoner painting body rustproof painting body finishing painting body second coat painting body parts (bumper, cylinder-block and other painting) body duster use	airless static air spray air spray powder
Home electric appliance industry	home electric appliance parts (TV, cassette tape, etc) painting lighting fixtures painting, refrigerator, washing machine and range coating, sound product painting	air spray
Home furniture and appliance industry	steel furniture and wood furniture painting, kitchen appliance painting, medical device painting	air spray static spray enamel coating
Office machine and equipment industry	calculator part coating locker, desk painting, copier coating	air spray
Agricultural machinery and tool industry, construction machinery industry, precision machinery industry	sewing machine parts painting, lens polisher coating tractor parts painting	air spray
Others	for washing of carrots freight car truck frame painting	

Grinding Robot 'GP-1'

Tokyo KIKAI SEKKEI in Japanese Vol 25 No 12, Oct 81 pp 81-84

[Article by Kazuo Minowa*, Sumitomo Heavy Industries, Ltd]

[Text] Initially, industrial robots were used for simple repetitious tasks such as loading and unloading work. However, with the development of control elements such as microcomputers, decelerators and actuators, the use of robots has broadened into dangerous work such as loading and unloading at a press, and work requiring high technology under an adverse environment such as painting, welding and grinding tasks.

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In this article, I will discuss a grinding robot (GP-1) system for grinding tasks in metal mold processing that requires precise surface accuracy.

This system was developed based upon the grinder robot[1] developed by Sumitomo Heavy Industries for shaving off black skins from castings. In addition to the grinding robot, an automatic inspector is introduced for inspection and assessment of the finishing accuracy of the worked surface (see Photo 1).

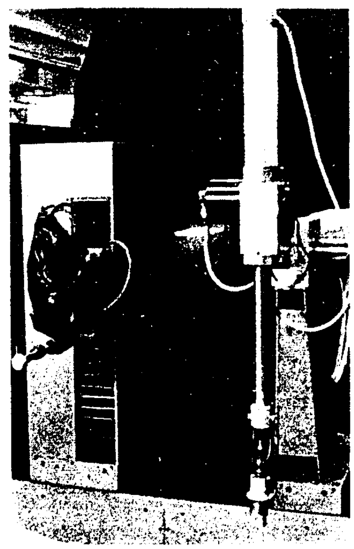

Photo 1. Grinding Robot and Inspector

Job Content

Metal mold processing methods vary depending upon the objects. Generally, for the processing of metal molds with a three-dimensional curves surface by cutting, the curved surface of the metal molds is first shaped using a ball-end mill. Then, finishing work (smoothing work) is carried out to remove cut marks from the ball-end mill. Subsequently, final finishing is accomplished using sandpaper.

The purpose of this system is to remove cut marks from both male and female metal molds shaped symmetric to a center axis. In this case, overgrinding of the cut marks results in an inferior product and insufficient grinding leads to a time loss in the process that follows. Accordingly, this system incorporates an inspector which measures the state of processing at its discretion, and operates the grinding robot which carries on the grinding work based upon the results of the inspection.

System Arrangement

This system is composed of a grinding robot, an inspector, a work setter and grindstone exchanger, and a control unit. The system arrangement is compact because each device shares the functions that often tend to be concentrated in robots, based upon the job analysis of the objective work. A layout of each device is shown in Figure 1, and specifications are shown in Table 1. The grinding robot and the inspector are installed on a common bed symmetrically to center axis A-A of the work setter. The grinding task is carried out in Work Area P, and inspection and teaching are conducted in Work Area I. Each device will be discussed.

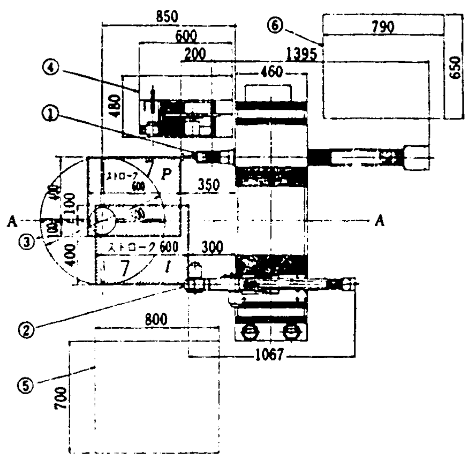

Figure 1. System Arrangement

Key:
(1) grinding robot
(2) inspector
(3) work setter
(4) grindstone
(5) controller
(6) oil source
(7) stroke

The grinding robot consists of a total of five shafts--three basic rectangular coordinate type shafts and shafts for elbow and twist of the hand. In reference to the driving system, all shafts are driven by an electric-oil pressure servo system. The general appearance of the robot is shown in Photo 1, and the general configuration is shown in Figure 2. The hand of the grinding robot is outfitted with a force detector which detects the grinder's pressing force and a commercial grinder. For the grinding operation, a simulation grind system is adopted, which grinds following the contours of the work surface while controlling the pressing force of the grinder, since the pressing force of the grinder is practically proportional to the amount of grinding (depth of cut).

Table 1. Grinding Robot System Specifications

Device and machine	Driving machine	Action range	Detector	Driving device	Position determination accuracy
Grinding robot	left to right up and down back and forth	500 mm 400 mm 600 mm	12-bit photo-electric encoder	electric-oil pressure servo valve-oil pressure cylinder	±0.5 mm
	twist elbow force detector	-30∼90° -15∼30° 0∼1.2kg	differential transformer		
Instru-ments	left to right up and down back and forth	500 mm 500 mm 600 mm	12-bit photo-electric encoder	electric-oil pressure servo valve-oil pressure cylinder	±0.5 mm
	simulation sensor surface inspector		differential transformer	DC motor	
Work setter	turn	360° endless	12-bit photoelec-tric encoder	electric-oil pressure servo valve-oil pressure cylinder	±0.7°
	tilt	0°,15°,30° 45°,60	code board	oil pressure cylinder	
Automatic grindstone exchanger	grindstone storage disk holds 20 grindstones on the circumference				
Weight	robot proper: 400 kg controller: 320 kg work setter: 200 kg automatic grindstone exchanger: 104 kg oil source: 545 kg				

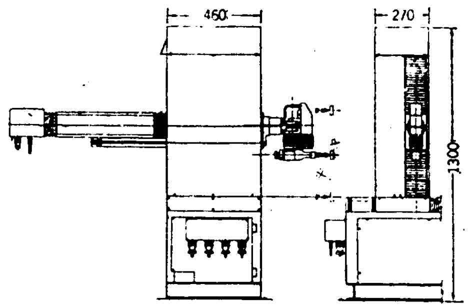

Figure 2. General Configuration of Grinding Robot

The inspector is composed of three basic rectangular coordinate shafts. Concerning the driving system, an electric-oil pressure servo system is used for the base, and an electric servo system is used for the other two shafts. The general appearance of the inspector is shown in Photo 1 (right side). The inspector serves two functions: a simulator which uses a simulation sensor attached to the hand and an inspector which uses a surface inspection device. These functions can be changed over by replacing the sensor on the hand. The transfer is simple. The general appearance of the simulation sensor and surface inspection device are shown in Photo 2. The simulation sensor is used during teaching. Automatic teaching is performed.[2] The surface inspection device is structured to measure the condition of the ground face on the surface by rotating a feeler independent of the direction of the cut marks. The resolution and feeler radius of the sensor are 3 μm and 10 mm respectively.

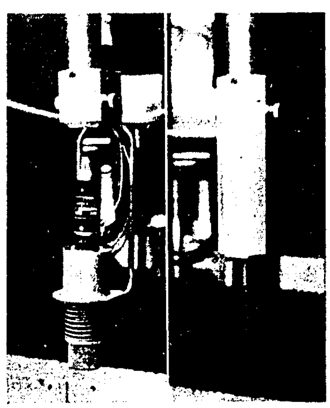
(a) (b)

Photo 2. Sensor of the Inspector

Key: (a) surface detection device
(b) simulation sensor

The work setter consists of two degrees of freedom that drive the turntable. The rotation of the turntable is endless and is driven by an electric-oil pressure servo system. The table can be tilted from 0 degrees (horizontal position) to 60 degrees at intervals of 15 degrees. Fixing, removing and positioning of work are all operated manually. Incidentally, positioning of the work is accomplished by utilizing key grooves in the work.

The grindstone exchanger is composed of a cassette disk, a base and a clamp. Its general appearance is shown in Photo 3. The grindstone used here is on a shaft, and it is fitted on the grinder through a collet chuck adapter. Two kinds of such a grindstone can be stored 20 each on the circumference of the cassette disk, and they are freely changed as required during the grinding operation. The timing of the grindstone exchange is determined on the basis of the results obtained from measuring the abrasion of the grindstones (measurement entails measuring the radius of the grindstones using a soft touch function which utilizes the force detecting device). Grindstones are exchanged by loosening the screw of the collet chuck after the adapter is fixed with the clamp. It takes approximately 15 seconds to complete the grindstone exchange.

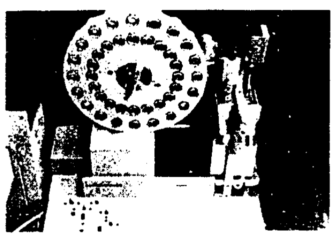

Photo 3. General Appearance of Grindstone Exchanger

Photo 4. Controller

The controller is composed of an upper minicomputer and lower three units of microcontroller systems (G-SVC, I-SVC and WS/EX). The general appearance of the controller is shown in Photo 4, and the arrangement is shown in Figure 3. The main functions of the minicomputer are communication with the lower microcomputers, point data control and interactive input and output processing. The lower three microcontrollers are assigned specially to each device and consist of a digital servo system. The interaction with the operator will be accomplished using a plasma display and push button (keyboard is for backup during errors). The plasma display instructs working steps and displays errors and the condition of each device. A cassette tape is used as a supplementary memory and stores teaching data.

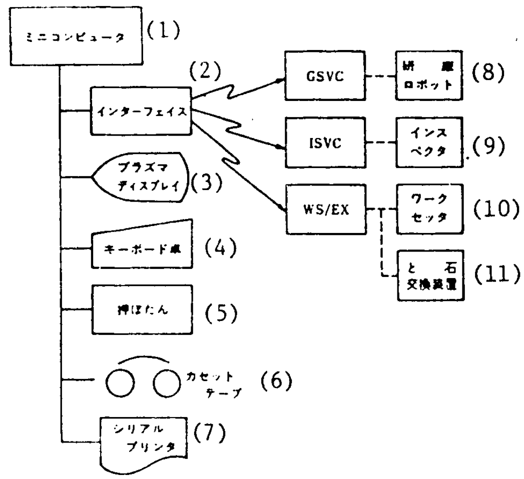

Figure 3. Arrangement of Controller

Key:
(1) minicomputer
(2) interface
(3) plasma display
(4) keyboard
(5) push button
(6) cassette tape
(7) serial printer
(8) grinding robot
(9) inspector
(10) work setter
(11) grindstone exchanger

Operational Method

The operational method of this system is comprised of a teaching mode that teaches working steps using a teaching panel and a grinding mode that executes the grinding work by reproducing the work steps. In the following, each mode will be explained. Incidentally, the grinding work is operated by a block grinding system that executes the grinding work block by block after alloting the grinding surface to the desired number of blocks.

1. Teaching Mode

Teaching is always conducted when a regeneration type robot is in use. This job directly relates to the quality of the product or the flexibility to meet changes in the work, particularly with regard to painting and grinding robots, which makes the need for a simple procedure for changing teaching and data very important.

This system is designed to simplify teaching by introducing automatic teaching through a simulation system and a line interpolation function. The teaching steps are shown in Figure 4. For the teaching of the grinding surface, the posture of the work setter for each block and the posture of the grinder at the position of the block's endpoints are taught using a teaching panel by driving the work setter and the grinding robot. Afterward, points within each block are taught by automatic teaching using the simulation sensor of the inspector. Therefore, the work at each block can be easily reoriented by merely changing

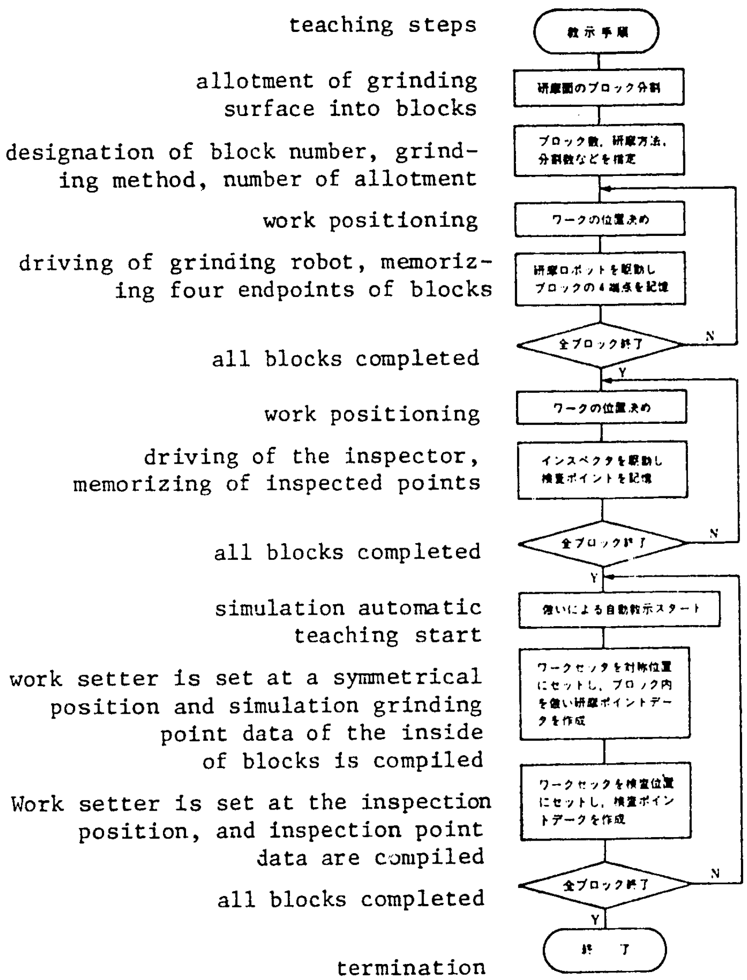

Figure 4. Teaching Steps

the endpoints. Incidentally, the points taught here are the position from which to approach the work during the grinding operation. When operating, the robot grinds the work while correcting the taught points by itself so that the pressing force of the grinder comes into compliance with the suggested force using the force detecting device.

2. Grinding Mode

The grinding job starts by operating the push button on the front panel of the controller according to the instruction of the plasma display after setting the work. At this time, if the work data is not contained in the minicomputer's memory, the corresponding data can be read from cassette tapes to carry out the job. A flow chart of the grinding operation is shown in Figure 5. In the

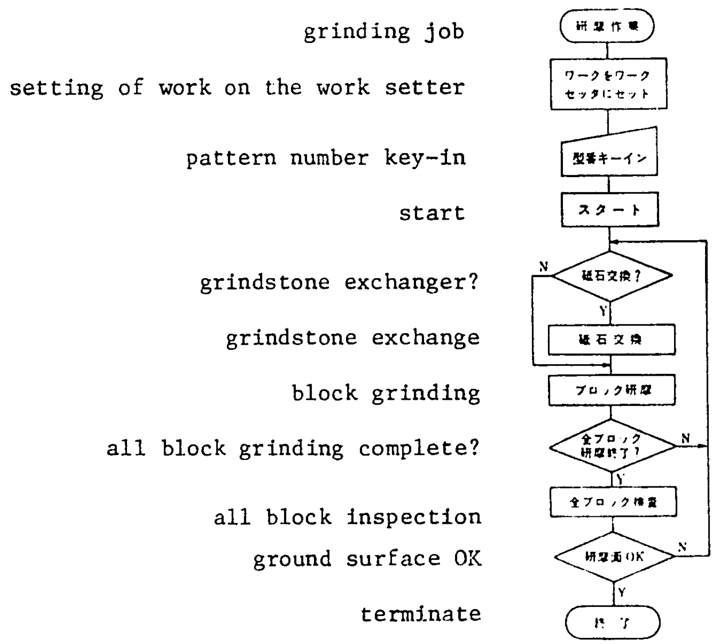

Figure 5. Operational Steps

grinding operation, all blocks are first ground twice. This procedure is practiced to shorten the work time, since the pressing force set at the initial stage will not incur excessive grinding in the first two applications. Afterward, the grinding condition (wave height of the cut mark) of each block is measured by the inspector, and the subsequent grinding task schedule will be decided based upon the results. The above steps are repeated until the desired surface accuracy is obtained.

Grinding Results

Regarding a grinding method which uses a grinder, generally, there is a method which grinds one line at a time as a grinding machine does, and there is a method which grinds the entire surface by random motion of a grinder. For a grinding task that requires precise surface accuracy such as the grinding of metal molds, the random grinding of the entire surface is more suitable. This system incorporates a weaving grinding which grinds by swaying the head of the grinder left to right. The cut marks on the metal molds used in this case as the work objects have undulations of approximately 100 μm. The appearance of the undulatory cut marks are shown in Photo 5, and the grinding results are shown in Photo 6. Photo 6 shows the ground state of a female metal mold with an opening of approximately 340 x 440 mm when the work was divided into 26 blocks (teaching block numbers 13, teaching point numbers 13 x 4, automatic teaching point numbers approximately 500). The maximum total grinding frequency and surface accuracy of the finishing were set at 3 and 31 μm respectively. The grinding results obtained under this condition showed an overall surface accuracy of 30 μm, and grinding frequency of 2-3 times.

Photo 5. Cut Marks

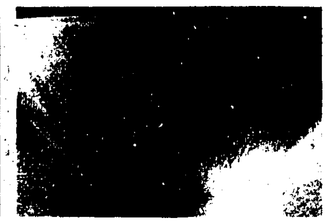

Photo 6. Ground Surface of Work

Conclusion

Whether or not the given functions [illegible] robot which is made to do a job such as a grinding robot can be fully utilized depends to a large extent on the know-how of the operator, unlike the conventional robot used for carrying objects. In particular, the precision grinding robot developed at this time requires know-how of an operator. This grinding system is currently being introduced to an actual production line and takes care of almost 80 percent of the grinding task. Meanwhile, know-how necessary for precision grinding is being accumulated.

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Nuclear Robot 'BILARM-83A'

Tokyo KIKAI SEKKEI in Japanese Vol 25 No 12, Oct 81 pp 85-88

[Article by Seiji Kawai*, Meidensha Electric Mfg Co, Ltd]

[Text] This is an introduction of the BILARM-83A robot which can skillfully handle a task mainly in a radioactive environment associated with nuclear power.

Generally, it is called a power manipulator. Recent models incorporate a microcomputer, and a robot-like application is being devised. However, the typical use of this machine is different from that of a robot at a mass production factory. It is not meant to handle repetitious simple tasks. Precisely, this is a handling machine which carries out unspecified maintenance work too difficult to be handled by automated systems in a radioactive or especially hazardous environment where man cannot work.

Slave Arm

BILARM-83A was developed by Meidensha with the guidance of the Power Reactor and Nuclear Fuel Development Corporation. In this machine, a bilateral servo mechanism is adopted to give a sense of force. On the other hand, since the joint closely approximates a human arm, its action range is very wide and it is very easy to use.

Photo 1 shows the slave arm. The standard cross-section of the arm is circular, and it is designed to have a safe and easy approach to the machines and equipment to be handled when it is in operation. Of course, the driving part is structured to contain all the wiring inside. The beautiful smooth external appearance is the result of function and miniaturization.

The power slave (PS) generally handles unspecified maneuvers through remote control by the power master (PM) operated by an operator rather than through a general playback operation. There are various support systems. The concept of the arm is shown in Figure 1.

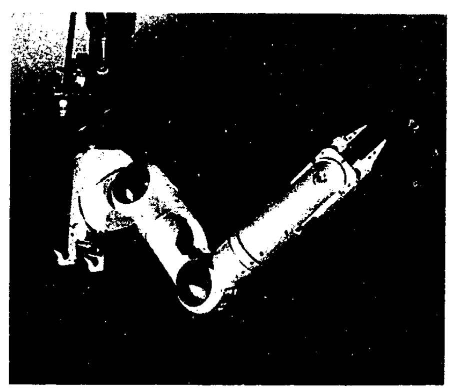

Photo 1. PS: Power Slave

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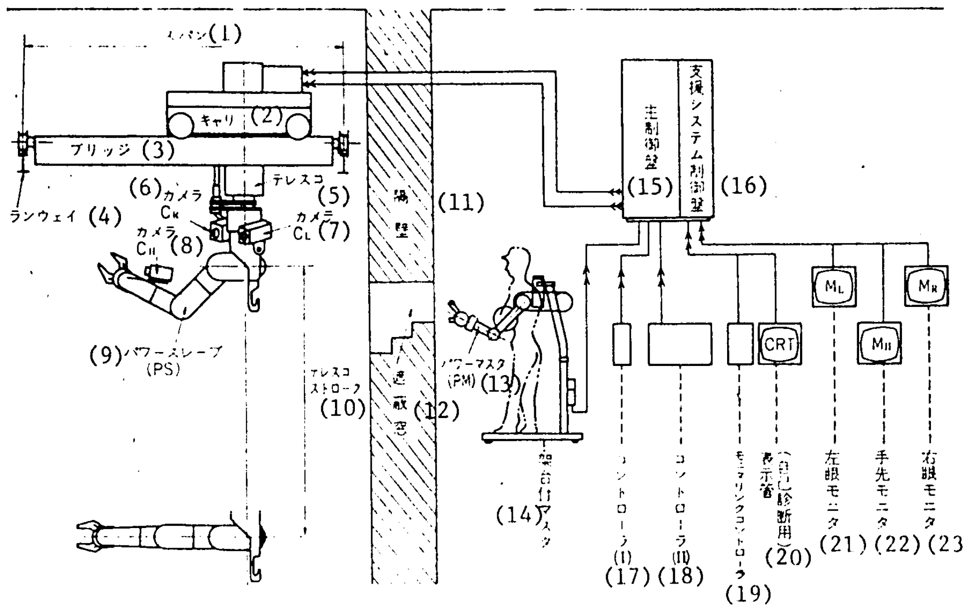


Figure 1. Concept of Main System

Key:

(1)	span	(9)	power slave	(17)	controller (I)
(2)	carriage	(10)	telescope stroke	(18)	controller (II)
(3)	bridge	(11)	dividing wall	(19)	monitoring controller
(4)	runway	(12)	closed window	(20)	display tube (self-diagnosis)
(5)	telescope	(13)	power master	(21)	left eye monitor
(6)	camera CR	(14)	master on pedestal	(22)	hand monitor
(7)	camera CL	(15)	main control panel	(23)	right eye monitor
(8)	camera CH	(16)	support system control panel		

The securing of vision is the most important element in a system such as this. Viewing the PS and the object to be handled in the sealed chamber through the window, an operator performs tasks within a range of several meters. Other visual support comes from two groups of ITV cameras: ITV camera CH that always secures a field of vision of the hand, ITV cameras CR and CL on the shoulder of the PS which are effective especially for remote-control tasks. Also, a monitor TV displays the work area. These shoulder cameras work by a servo universal head. A system has been developed whereby a PS operation signal is processed by a microcomputer, and hand movement automatically follows. In addition, automatic diagnosis and warning of the PS work condition and operational steps can be displayed on the display tube.

Likewise, as a typical PS travelling system, three-dimensional travel is made practical by a telescope that moves up and down and a carriage and a bridge that travel sideways and straight.

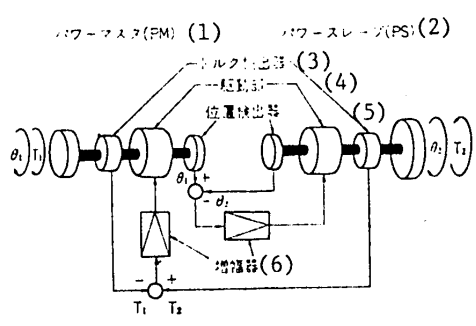
With these systems combined, it is possible to carry out remote control of the tasks in every corner of the space in the sealed chamber, but the efficiency is slightly lower than if the job were directly handled by a human. Nevertheless, considering that it is often not possible for a huamn to do the job in radioactive conditions, and if the operation by a human entails decontamination steps, these robot systems are obviously effective and useful.

Actuator and Sensor

The PS actuator is small and light; it uses a DC motor which gives high torque. The DC motor used is a special kind which has passed inspection after a radiation test with carefully selected insulating material and lubricating oil, because radioresistance is demanded of the motor. The PS has seven degrees of freedom from shoulder to wrist and one degree of freedom that permits horizontal movement of the fingers; the DC motor consists of only two types, and innovative gearing is designed for the decelerator. Small size and light weight are also required of the decelerator. A harmonic drive component is used for all joints.

For the decelerator output of the PS actuator, a potentiometer is integrated as a position sensor. Power transfer in each joint is extremely simple. A unit which is a part assembly of the DC motor, decelerator and potentiometer is contained in a tubular link of each joint, as seen in Photo 1. In this structure, the PS is directly driven only by gears which are highly reliable compared to conventional models, which are driven by chains and wireropes. Also, during operation and traveling, it is easier to manipulate the power slave because of the absence of the protruding driving mechanism on the arm.

Among the degrees of freedom given to the PS, the torque of the actuators, i.e., the three degrees of freedom counting from the fingers--grip, wrist bend and wrist twist--is checked by a built-in load cell. These three degrees of freedom on the power master side are arranged the same as on the PS side. They work as sensors that feed back the load reaction force generated on the PS side to the operator, contrary to transferring the force of the operator proportionally to the PS. Control of the sense of force such as this is called bilateral control, and its principle and structure are shown in Figure 2.



Key:
(1) power master
(2) power slave
(3) torque detector
(4) driving part
(5) position detector
(6) amplifier

Figure 2. Bilateral Control

Several bilateral systems such as this have been researched for some years and put into practice using a relatively simple oil pressure driving mechanism. A bilateral control for nuclear robots, the origin of the research, however, is still in the development stage in every country. One of the reasons for this is that all that were developed previously were not fully comparable to the purely mechanical bilateral sense of force obtained by the conventional "master/slave manipulator" regularly used in nuclear power research facilities. However, recently attention has been drawn to an electric-driven power manipulator with a bilateral sense of force and good movability due to the scale-up of nuclear industrial facilities and the strong appeal to reduce the radioactive exposure of workers, and BILARM-83A developed by our company has been adopted.

When this control is adopted, vision is likely to become insufficient in large-scale facilities, but an operator can prevent irrational operation by using the sense of force in such a case. Breakage of systems on the other side or breakage of the PS itself can be prevented. However, at the present stage of progress, in order to avoid the complication of control lines and the complication of the arm tare balance compensation, the degrees of freedom are limited to three in the hand which are considered most effective for the job. Position control is provided only for the elbow and the shoulder.

Application of Microcomputer

Regarding application of the microcomputer, it is sometimes used for playback control, but other applications are more prevalent since its typical use is for unspecified tasks with little repetitious driving. For example, when letting two ITV shoulder cameras automatically follow the movement of the hand, elbow and shoulder signals are used for arithmetic processing by a microcomputer among the PS potentiometer signals--excluding signals beyond the wrist, which does not move a lot when viewed from the shoulder--and the position of the hand viewed from the shoulder is obtained. The results are used for drive control of the electric universal head with three degrees of freedom--rotation, elevation and twist--which makes it possible for the two ITV cameras, which are equivalent to left and right eyes, always to follow the hand of the PS, automatically placing it in the center of the field of vision when an operator operates the PM.

It appears that an attachable camera mounted on the wrist such as Camera CH in Figure 1 is fully satisfactory to get a constant view of the hand. However, a camera placed in such a position serves only as a supplementary vision to the operator, because the monitor pictures turn upside down with the turning of the wrist. Incidentally, as a simpler method of using the ITV than the conventional generally practiced method, actions of the PS can be followed with an ITV camera fixed on virtually orthogonal walls that run in two directions using a zoom lens and a remote control universal head. In this system, the entire picture of the PS and partial enlargement of the hand are possible if necessary. However, an ITV camera operator is needed in addition to the PS operator. It not only takes time to follow the PS movements, but the operator must construct the movements judging himself as to the correct direction from which the monitor pictures were taken. Specifically, when the PS rotates at the shoulder, left and right senses totally reverse at a turn of 180°, and usually an operation miss is likely to occur because the operator cannot handle this coordinate transformation by intuition.

As an additional application of microcomputers, we are developing a system which conveys to an operator organized operation support information including operational steps and overload warnings.

Standard Specifications and External Dimensions

Standard specifications for the PS are shown in Table 1. Also, Figure 3 shows one example of a traveling system and the external dimensions of the assembled system.

Table 1. Standard Specification of PS

Item	Active part	Action value: Master	Action value: Control box	Action speed
1	Shoulder (vertical shaft) turn	90°	400°	8°/S
2	Shoulder (down-right side) sway	90°	160°	8°/S
3	Shoulder (down-forward-up) sway	165°		8°/S
4	Elbow turn	150°		10°/S
5	Elbow bend	135°		10°/S
6	Wrist twist	135°	250°	
		400 kg·cm		30°/S
7	Wrist bend	90°	180°	
		400 kg·cm		30°/S
8	Finger standard parallel link opening and closing	MAX 127 mm MAX 100 kg		MAX 15 mm/sec
9	Composite handling load	FULL RANGE		25 kg
		Downward and other positions where force is easily applied		50 kg
		Suspended downward from arm		100 kg
10	Under shoulder hook handling			450 kg
11	Telescope extension and retraction	400 mm		0.4~4.5 m/min
12	Required power source	200/220V, 50/60Hz		approximately 6 kVA

Incidentally, the PS can be operated by intuiton by a PM or it can be operated joint by joint, in an operational angle range to which normally an operator cannot physically bend, by a separate accessory controller. Therefore, the action values of both ways are shown in Table 1.

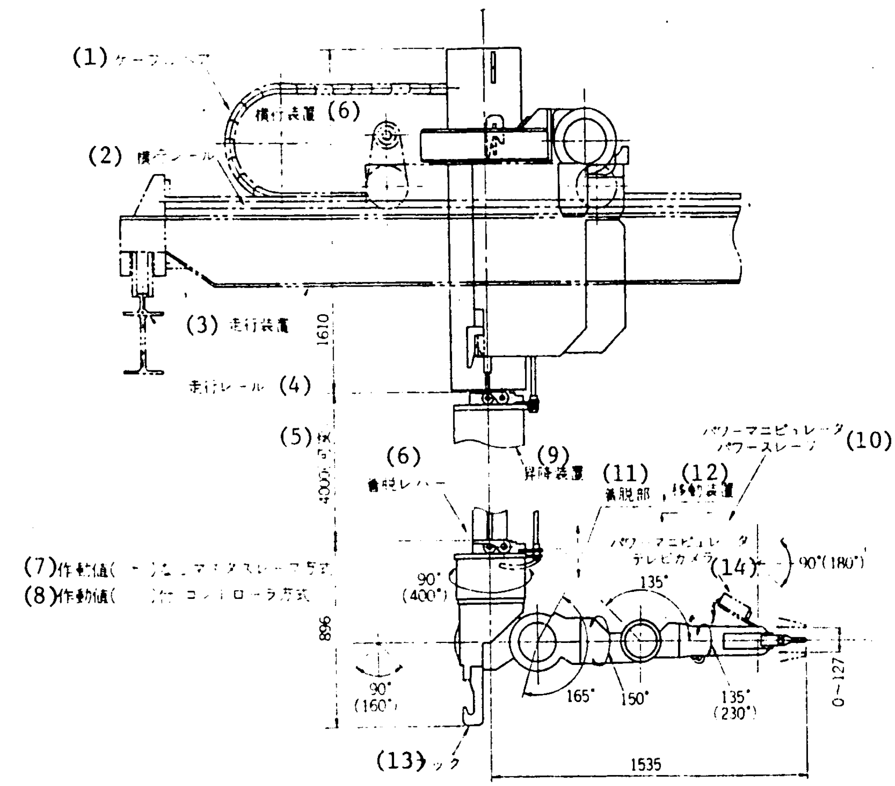


Figure 3. Slave Side, External Dimensions

Key:

(1) cable bearing
(2) side travel rail
(3) run system
(4) run rail
(5) variable
(6) attaching lever
(7) master slave system, action values without bracket
(8) control system, action values in bracket
(9) up and down system
(10) power manipulator power slave
(11) attaching site
(12) travelling system
(13) hook
(14) power manipulator TV camera

The action speed indicated is the speed achieved without load. Speed changes up to about 1/10 can be accomplished without staging the process when the PM or the controller is operated slowly. However, on the high speed side, with an operation at a speed above those indicated in Table 1, the PS will follow at a slightly lagging pace.

Whether to control by a PM or by a controller can be decided for each joint. This arrangement is very convenient, for example, when it is necessary to hold a specific joint stationary during PM operation; that joint alone can be switched over to controller operation. Even if the PM inadvertently operates the joint, that particular joint will not be activated but will maintain a fixed position.

Facts of Application

The BILARM-83A model was developed not as a general industrial robot but as a robot that can handle special unspecified maintenance tasks in special places mainly in a radioactive environment. Heretofore, actual use has also been limited to maintenance purposes in nuclear related facilities. Recently, application to assist regular checkups at power plants, in particular among the same nuclear related facilities, has been investigated. New applications are drawing attention one after another. Details of use cannot be disclosed at this time since we are now at the verification stage by the users. The operability of the robot is, however, rated highly. Based on the shipping results to date, although the PS has a comfortable margin of freedom--eight degrees of freedom as a standard--the objective task can be accomplished even if three-five degrees of freedom are eliminated for some applications.

Indeed, there has been an inquiry for a specific-use robot, and we are planning for the development of this robot. Various characteristics are notable in the BILARM-83A robot, which is modeled after a human arm and is provided with more degrees of freedom to handle unspecified tasks than general industrial robots. The greatest characteristic is what is called the joint configuration, which allows the PS to take the most ingenious postures of all robots, permitting the robot to do extensive work almost exactly following the form of the operator's arm.

In the actual handling of the work, special tools for screwing and unscrewing of bolts up to about M 20 by an impact wrench and various tools are necessary. We are united with the users in our pursuit of developing advanced robots.

Conclusion

Several sets of the BILARM-83A model have already been delivered to the Power Reactor and Nuclear Fuel Development Corporation, and are demonstrating the initially expected efficiency. I would like to express our deep appreciation in this paper to everyone in the corporation who rendered specific guidance regarding know-how in actual application. Incidentally, this model was developed for special use, but the use of the machine will be gradually broadened with the help of the users. All inquiries will be greatly appreciated.

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