The Research on the Feasibility of Robotizing Work at Steelworks*

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I. Introduction

The use of robots has become so popular that the 1980s may be called "the industrial robot age". Amongst others, technological innovation in micro-electronics has given birth to the brain robot which in turn has brought robotization even closer to us. On the other hand, the iron and steel industry is now faced with a number of problems, such as the enhancement of productivity, reduction of cost, improvement of quality, all which must be achieved by successfully coping with the changing labour situation being created by the increase in the number of old people under its employment, wage increases, labour shortage in unfavourable environmental or hazardous operation areas and so forth.

It is against this background that Robot Research Working Group was formed with the participation of the fourteen companies (7 each from the steelmakers and the machinery makers), member companies of Rolling Mill Engineering Research Subcomm. The working group has since been carrying on its activities with "Steelworks Robotization" as its theme.

The working group did not aim at any specific developmental activities in either hard or soft wares relating to robots, but has conducted a survey on the actual use of robots in steelworks as well as their needs for robotization by collecting data based on questionnaires. Its study, therefore, just covered the aspects which will give suggestions on future robotization planning and did not extend beyond that.

The result of the study was reported to the 27th meeting of Rolling Mill Engineering Research Subcomm. itemized as follows.

1) Actual condition of use of robots in steelworks
2) Interpretation of the term, “robot” in steelworks
3) Actual conditions on robotization needs in steelworks
4) Evaluation of feasibility of meeting robotization needs in steelworks
5) Technical problems in realising robotisation
6) Trend of robot technology

Of these, Items (1), (3) to (5) will be reported in a summarized form as hereunder.

II. Method of Survey

The survey was made by distributing questionnaires to 25 works of the 7 steelmakers who are members of Rolling Mill Engineering Research Subcomm. The questionnaires were prepared based on the following concepts:

1) In order to identify actual robot use conditions in steelworks and perception of robots in the iron and steel industry, information is to be sought on those equipment and machines which are currently in operation in steelworks and which are recognised as robots or which look like robots.

(2) In order to identify the need in future steel plant robotization planning, information is to be sought on those types of works currently relying on human labour for which robotization is being awaited or those types of works currently done with machines but which may be done more efficiently with robots.

The survey was conducted by asking for entry in formats containing the following items:

i) Name of operation (or name of machine or equipment)
ii) Outline description of operation (purpose, content, procedure and keypoint of operation as well as operational condition and rough sketch of the work)
iii) Scope of robotized operation
iv) Aim of robotization
v) Condition for robotization and function of robot (environmental conditions, size and weight of the work object, operation cycle time, working conditions, etc.)
v) Technical problems to be solved
vii) Others.

In order to make its robotization information more concrete following the above first series of survey, the working group has incorporated in its report the findings from individual enquiries made by its members (in the second series of survey).

III. Summary of Answers to Questionnaires

Answers obtained to the questionnaires covered 49 “actual robot use” cases and 110 cases relating to “robotization needs”. The following is the summary:

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(854) Report
1. **Process-wise Analysis**

The result obtained by classifying collected data by types of processes adopted at steelworks is as shown in Fig. 1.

Processes with a higher percentage of robot use at steelworks are those under tough environmental conditions ridden by high temperatures, dust, harmful gas, etc., namely, blast furnace and converter operations and those in the final product stage, i.e., cold rolling processes where labour intensive auxiliary operations play an increasing larger role.

As regards "robotization needs", as is the case with "actual robot use", the labour intensive auxiliary operation is eyed as a likely field for robotization.

2. **Operation-wise Analysis**

Classification by types (purposes) of works has given a result as shown in Fig. 2.

In both "actual robot use" and "robotization needs", this type-wise breakdown points to greater interest in robotization being directed towards end processes and off-line operations such as finishing lines rather than main line operations.

High rate robot use at steelworks is in the following operations:

1) Assembling and fitting work (dismantling and fitting work including blade changing, capping and decapping, etc.)
2) Marking and labelling operation
3) Furnace lining work (refractory removing work included)
4) Cleaning and clearing work (crop disposal, slag removal, etc.).

These, it may be said, are the cases of robots being used in comparatively simple and repetitive operation.

As regards "robotization needs", the trend is similar to that shown in "actual robot use", but with

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**Fig. 1.** Process-wise trend.

**Fig. 2.** Operation-wise trend.

**Fig. 3.** Trend by aim of robotization.
an increased importance being attached to quality, there is a sign that application is being expanded to sampling and cleaning and clearing operations including removal of impurities of slag and so on and disposal of odd pieces from finishing processes.

3. Analysis by Robotization Aims

The result obtained by classifying data by robotization aims is as shown in Fig. 3. Conspicuously, both in “actual robot use” and “robotization needs”, rationalization, particularly, manpower saving is given a top priority as an aim of robotization, thereby making improvement of labour conditions the second choice.

IV. Observation on Steelworks Robot Use

An attempt was made to rearrange data from questionnaire answers on “actual robot use” according to the JIS B0134 robot classification method. As a result, it turned out that out of the 49 cases covered therein, 11 cases did not involve the use of manipulator functions. These were the cases of automatic bundling machines, unmanned carrier, automatic surface defect detectors, etc. all of which had to be regarded as specific functional automatic devices and reclassified accordingly. Thus, the “actual robot use” in steelworks is as shown in Fig. 4 and Table 1. Namely:

(1) Most of the robots currently in use at steelworks are what JIS main classification defines as manual manipulators and fixed sequence robots. It seems, therefore, that use of high-level robots will be the matter for future as far as steelworks are concerned.

(2) Works for which robotization is in a comparatively advanced stage are assembling, fitting, marking/labeling, slag removing and furnace lining operations. Facts common with these operations relating to robots are that most of the robots used there do not have a function of sensor which role is only being played by

![Fig. 4. Distribution of questionnaires answers by types of robots. (Actual robot use case)](image)

<table>
<thead>
<tr>
<th>Type of work</th>
<th>Manual manipulator</th>
<th>Fixed sequence robot</th>
<th>Variable sequence robot</th>
<th>Playback robot</th>
<th>N.C. robot</th>
<th>Brain robot</th>
<th>Total No. of cases (38 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembling, fitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10 cases</td>
</tr>
<tr>
<td>Marking, labelling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 cases</td>
</tr>
<tr>
<td>Cleaning, clearing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 cases</td>
</tr>
<tr>
<td>Furnace lining (dismantling)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 cases</td>
</tr>
<tr>
<td>Scratch treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 cases</td>
</tr>
<tr>
<td>Sampling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 cases</td>
</tr>
<tr>
<td>Welding, gas-cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 cases</td>
</tr>
<tr>
<td>Piling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 cases</td>
</tr>
<tr>
<td>Conveying, loading, unloading</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 cases</td>
</tr>
<tr>
<td>Forging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 cases</td>
</tr>
</tbody>
</table>

* : No relevant data
Number of cases represented by circle diameter
men, secondly that the scope of work assigned to robots is such that they do only a very limited part of the whole work thus excusing themselves from the role of main actors and thirdly that they are being used in fairly simple and repetitive types of works.

(3) Here, the question of how the term “robot” is interpreted comes up for consideration. Stripper cranes, hydraulic shovels, fork lifts, etc. being used in steelworks may fall in the category of manual manipulators but none of these was included in the data supplied on “actual robot use”. It thus seems that there is no idea to recognize as robots this kind of machines which can only be regarded as specific functional machines.

V. Observation on “Robotization Needs” in Steelworks

Since the data collected on “robotization needs” showed that there is a difference from one works to another in robot installing conditions or in application of peripheral technologies, etc., feasibility of robotization was assessed based on average performances available today and assuming simplified operations and as simple a structure as possible.

Feasibility evaluation was made of each case of “robotization needs” in accordance with the 5-step evaluation criteria specified in Table 2, the result of which is shown in Fig. 5. It shows about 60% of the cases having technical problems whereas no-problem cases both technically and economically account for only 5%. It is thus seen that further researches and development efforts are needed for steelworks robotization.

1. Image of Robots in Steelworks

Based on the image of robots as described above, an attempt was made to set up Specified items for robots, apply statistical treatment to the same and give a trend analysis. The result indicates that while in steelworks there were few who needed anything special where the structure of robots was concerned, there exists a trend calling for higher technologies that are available today in respect of soft wares which are essential part of high-class robots.

1. Specified Items for Works

The weight carried by a robot ranges from the lightest measurable in grams like that of a label to as much as 2000 kg in some cases, but those below 50 kg per case are predominant as shown in Fig. 6. Operations entailing heavy lifts are parts replacements in assembling and fitting works or trimming for sample materials which are very limited in number. Sectional shapes of work objects held by robots are varied, some circular, others rectangular, L-shaped and so forth, the distribution of which is shown in Fig. 7.

<table>
<thead>
<tr>
<th>Feasibility</th>
<th>Symbol</th>
<th>Supplementary explanation (concept)</th>
<th>Reason for difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Already industrialized</td>
<td>⊙</td>
<td>Applicable by introducing existing robot or with partial modification</td>
<td>—</td>
</tr>
<tr>
<td>Technically developed; under</td>
<td>△</td>
<td>Checking peripheral technology, cost saving expected (to function as part of group system)</td>
<td>—</td>
</tr>
<tr>
<td>economic evaluation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under technical study</td>
<td>▲</td>
<td>Technological development in progress</td>
<td></td>
</tr>
<tr>
<td>Laboratory research started</td>
<td>△</td>
<td>Technically possible, but economic merit yet to be proved</td>
<td></td>
</tr>
<tr>
<td>Need study</td>
<td>⊙</td>
<td>Technically difficult at present</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Evaluation criteria for feasibility of realisation.
2. Specified Items for Body

As for the movement of body, though the degree of freedom depends on the ambient conditions under which the robot is put to use, analysis was made here of its sideway, back-and-forth and up-and-down movement strokes. The distribution of these strokes is shown in Fig. 8 from which it may be assumed that the representative strokes are 3 000 mm or below along both X and Y axes and 1 000 mm or below along Z axis.

3. Specified Items for Robot Arms

Arms are an essential part of the robot and specified items were studied assuming turning and back-and-forth movements to be its representative function. Of these, the back-and-forth stroke of 2 000 mm, as shown in Fig. 9, is considered sufficient to cover most of the operations.

4. Specified Items for Robot Wrists

The degree of freedom in designing robot hands is an important study item. Shown in Table 3 is the result of analysis made in respect of each type of operation. It will be seen here that no wrist freedom is necessary in the case of loading/charging, cleaning and clearing operations (particularly, slag removing work) whereas a high degree of freedom is required in assembling–fitting, marking–labelling, sampling and other such operations as will involve positioning control.

5. Specified Items for Positioning Accuracy

The analysis result concerning accuracy is as shown
in Fig. 10. Accuracy within ±1 mm is required in welding, gas-cutting, deburring and other similar operations though these cases are comparatively few.

6. Environment

Environmental conditions surrounding robots are as shown in Fig. 11. There are a number of cases where dust is a problem but very few cases of temperature or humidity being so.

2. Technical Problems for Robotization

Shown in Table 4 are a distribution pattern for feasibility of realisation relating to "robotization needs" and particulars of technical problems. As a whole, matters related to sensing figure prominently. This, viewed in the light of "actual robot use" shown in Fig. 12, may predictably prove an important factor in pushing forward robotization. Further study and development efforts are desired in this field of sensing, particularly, in relation to positioning and force. Technical problems facing each type of operations at steelworks are discussed below.

(1) Assembling and Fitting Operation

This includes removal and setting, that is, replacement, of components, capping and decapping or placement and removal of tools. In other words, it is a kind of positioning operating the nature of which is such that it is comparatively free from technical problems and that the "robotization needs" are high.

In this type of operation, it may be pointed out, developing highly sensitive touching sensors is an important technical necessity if a proper grip feel for holding different shapes or a correct sensing of even a slightly deviated positioning is to be achieved.

(2) Charging Operation

This type of operation includes loading a container with, for instance, steel plates, uniform powder spraying or inserting spacer between certain things most of which do not require very precise positioning. It is, therefore, considered possible to take care of these operations with a combination of presently available technologies and technical know-hows, yet it will be necessary to study further peripheral techniques/technologies and try to improve working systems, etc.

(3) Marking and Labelling Operation

This type of operation comprises direct imprinting on products and semi-finished products, pasting labels onto predetermined positions and in predetermined directions and coating. Among other things, development of a sensor capable of identifying even the same series of colouring will be important so that uneven coating may be detected.

(4) Piling Operation

This type of operation consists of piling of crop of products, plates and like products at predetermined locations or extracting of only selected pieces from a line of products being delivered on a conveyor system. As a technical problem, study of a structure of sufficient rigidity and capable of a function to allow faster movement is recommended inasmuch as it will be necessary to handle dead weight items with a sufficiently high speed to match that of the conveyor belt.

(5) Furnace Lining Operation

Its object being all kinds of refractory structures and installations, this operation includes dismantling and piling of refractories and bricks, mortar spraying, etc. As this operation has to be carried out in high temperatures and dust and also entails transport of heavy items, robotization has been a subject of study since long from the viewpoint of improving labour conditions. The technical problem here will be profile measurement in high temperatures, joint filling between bricks, smooth finishing of mortared surfaces and holding of abnormally shaped items.

(6) Scratch Treatment Operation

This is the operation to detect surface scratches of products or semi-finished products and remove them with a grinder or by means of scarifying. For scratch detection, there are already in use fairly fast devices using visual sensors, but the future task will be to develop such robot as is capable of identifying the degree and extent of a variety of scratches (depth and direction) and of acting on such findings accordingly.

(7) Boring and Filling Operation

This is the operation to remove or apply fills from
or to holes and is similar to the assembling and fitting operation. It does not require any high degree of accuracy and there is technically not much to develop in this sector.

(8) Deburring Operation
This operation includes bevelling of angular and round ends and removal of burr from cut faces with a grinder. There is a question of dimensional accuracy of the work object or of locating sensors. Unless a high degree of operational efficiency is to be sought, however, chances of robotization are high. Here, the future technical problem will be to secure a higher degree of accuracy of the sensor to detect shape, location or pressing force and also provide a function to allow faster movement.

(9) Sampling Operation
The operation includes extraction of products test pieces and molten steel or ore samples for chemical composition analysis at the melting process. One of the technical problems in this type of operation will be, for instance, development of a device capable of a coordinated movement of both hands to hold and gas-cut samples for test pieces or to grab and take out moving objects by following the movement of such objects.

Table 4. Operation-wise feasibility of realisation and technical problems.

<table>
<thead>
<tr>
<th>Type of operation</th>
<th>Realization feasibility</th>
<th>Technical problem (apply to $\triangle$, ▲, ×)</th>
<th>Main problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assembling, fitting</td>
<td>◊ ○ ▲ ▲ ×</td>
<td>B E S</td>
<td>Development of sensor</td>
</tr>
<tr>
<td>2. Loading/Charging</td>
<td>◊ ○ ○ ▲ ×</td>
<td>O O O</td>
<td>Image identifying sensor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Identification of same colour series</td>
</tr>
<tr>
<td>3. Marking, labelling</td>
<td>◊ ○ ○ × ×</td>
<td>O O O</td>
<td>Detection of degree/Extent of scratch</td>
</tr>
<tr>
<td>4. Piling</td>
<td>▲ ○ ○ ▲ ▲ ×</td>
<td>▲ ▲ ○</td>
<td>Higher speed of movement</td>
</tr>
<tr>
<td>5. Furnace lining</td>
<td>▲ ○ ○ ▲ O</td>
<td>O O O</td>
<td>Identifying sensor, assembling,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>smooth finishing</td>
</tr>
<tr>
<td>6. Scratch treatment</td>
<td>▲ ▲ ○ ○ ×</td>
<td>O O O</td>
<td></td>
</tr>
<tr>
<td>7. Boring, filling</td>
<td>▲ ○ ○ ▲ ▲ ×</td>
<td>O O O</td>
<td></td>
</tr>
<tr>
<td>8. Deburring</td>
<td>○ ○ ○ ○ ×</td>
<td>○ ○ ▲</td>
<td>High-accuracy shape identifying</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sensor</td>
</tr>
<tr>
<td>9. Sampling</td>
<td>▲ ○ ○ ○ ○</td>
<td>O O O</td>
<td>2-hand operation (coordination)</td>
</tr>
<tr>
<td>10. Welding, gas-cutting</td>
<td>○ ○ ○ ▲ ×</td>
<td>O ○ ▲</td>
<td>High-accuracy shape identifying</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sensor</td>
</tr>
<tr>
<td>11. Cleaning, clearing</td>
<td>▲ ○ ○ ▲ O</td>
<td>O O O</td>
<td>Undefinable shape identifying</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sensor</td>
</tr>
<tr>
<td>12. Conveying, loading, unloading</td>
<td>▲ ▲ ▲ ▲ O</td>
<td>▲ ▲ ○</td>
<td></td>
</tr>
<tr>
<td>13. Others</td>
<td>▲ ▲ ○ ○ ○ ×</td>
<td>O O O</td>
<td></td>
</tr>
</tbody>
</table>

Explanation of symbols
◊ Industrialized
○ Technically developed, under economic evaluation
△ Under technical study
▲ Laboratory research started
× Need study

![Table 4](image)

Fig. 12. Robot use and needs sensing trend.

- **B**: Brain: 1. Cannot use due to low work accuracy 2. Sensor selection unacceptable
- **E**: Effect: 3. Required accuracy high 4. Cycle time too fast 5. No good structure available
- **S**: System: 6. Unusable due to environment (Temperature etc.) 7. Peripheral technology poor
There exist problems here as, unlike machinery assembly, “all to a high degree of precision” practices are not common in the steelworks welding and gas-cutting operation. Since work objects are not getting required accuracy, development of a high-accuracy shape identifying sensor is desired.

Cleaning and Clearing Operation

This type of operation comprises cleaning of the inside and outside of pipings and ducts, removal of slags and other wastes, orderly and well-aligned piling of products, etc. Since the special feature of this operation is that it often has to deal with objects of undefinable shape and yet has to choose between the needful and the other, it is desirable to develop a high-precision identifying sensor that can discriminate between the removable and the object to be cleaned.

VI. Conclusion

The achievements of the Robot Research Working Group are summarized below:

(1) While there are various views taken about the definition or interpretation of the term “robot”, the investigation made into actual robotization performances at steelworks based on the JIS definition revealed that manual manipulators are predominant and that application of robots to a more mental work is yet to be realised.

(2) The survey has further proved that, of all the processes in steelworks, there is little need for robotization in what is called the main line processes partly because machines with specialised functions or automatic operations have been actively introduced into those processes, whereas the finishing process or off-line auxiliary operation is being eyed as the more likely field for robotization.

(3) According to the “robotization needs” analysis result, a number of cases stands a good chance of robotization from a technical standpoint partly because there were in the past few instances where robots were used for handling heavy lifts—the very image of the steel industry—or for high-speed treatment.

(4) The technical task for expanding application of robots in steelworks would be to develop sensor, study development of a structure capable of coordinated movement using both hands and so on.

(5) Information on “robotization needs” was sought assuming “a robot in place of human labour”. If production system improvements are considered taking robots into account, hopefully, their use rate at steelworks will become even higher.

Since conditions for robotization differed from one works to another such as layouts, the way information was made available, installed structures, environments, etc., the working group could not go so far as to make specific suggestions as might have been expected, but it is hoped at this time that its report may be made use of by each company to fulfill “robotization needs” effectively and in a manner suitable to the respective conditions.