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# Advanced High Precision of Bar Inspection and Conditioning

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**Abstract**

***Special steel bars are worked secondly and thirdly by customers, and used in the critical safety components of automobiles, among other applications. So it is necessary to inspect and condition rolled bars accurately piece by piece before shipping, and it is very important to manufacture bars to maintain their traceability. To meet these needs, Muroran Works has directly linked rolling and finishing processes by utilizing an automatic bar buffer warehouse, and has automated surface inspection of bars and improved their detectability. These improvements have reducing the scratches by cutting the number of times the bars are handled, have advanced surface inspecting accuracy by automating manual inspection, and have enhanced bar quality. NS Bar & Wire Co. LTD, established in 2005, has adopted a high precise surface inspecting equipment and has built as high bar quality assurance system as Muroran Works has. An overview of these quality improvements is presented below.***

## 1. Introduction

Special steel bars are secondarily and tertiarily worked at customers for use as automotive safety component members or other parts. Rolled steel bars must therefore be rigidly inspected and conditioned in their production line before shipment. At the Rolling Mill of our Muroran Works, as many as some 800,000 steel bars are handled monthly; the assurance of their traceability is very important. Quality requirements for steel bars have been increasingly sterner and diversified, and there has also been an increasing requirement for the guarantee of all bars and overall length of bars supplied. Our methods to meet such requirements are also sophisticated.

To meet the increasingly rigid requirements for inspection and conditioning accuracy, we at Muroran Works directly linked the rolling and the finishing processes using an automated bar sorting warehouse and automated the bar surface flaw inspection process, for precision improvement. By these practices, we have achieved quality improvements, including the reduction of handling-originated bar surface damage by virtue of the reduction in the number of bar handlings, and the enhanced surface flaw detection accuracy owing to the inspection automation in place of the inspection by human perception.

On the other hand, steel bar consumption has been increasing in automobile and other industries. In 2005, we established a new bar production center, NS Bar & Wire Co. LTD (NSBW), within the premises of Nakayama Steel Works, Ltd. Achievements at our Muroran Works along with a high-precision surface flaw inspection system were introduced into NSBW to hold the product inspection system of NSBW at the same level as that of Muroran Works. The quality improving measures introduced above are outlined in the following sections, mainly referring to actual examples at Muroran Works.

## 2. Automatic Steel Bar Sorting Warehouse System[1)]

### 2.1 Problems of and solution technology for rolling-conditioning-shipping linkage

Special steel bars must be inspected and conditioned in a cold state after they have been hot-rolled, since a high level of quality assurance is required for them.

Conventionally, rolled steel bars were temporarily bundled, tagged, temporarily stored in pile in a yard, craned one bundle by one bundle from the top of the pile of bundles, conditioned, sorted for destinations, and shipped as shown in **Figs. 1** and **2**.

The most difficult problem among the problems of direct linking

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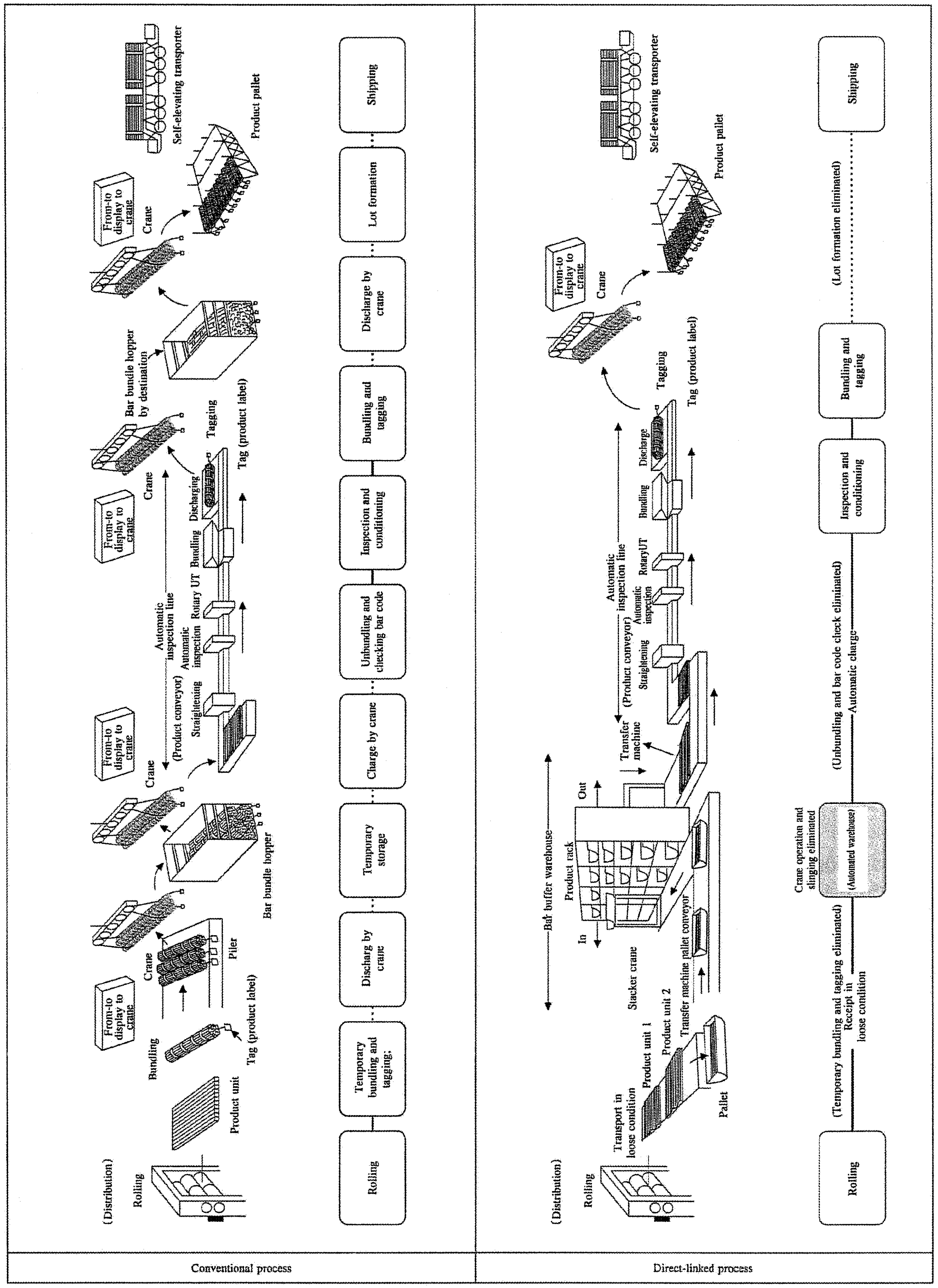


**Fig. 1 Special steel bar production processes**

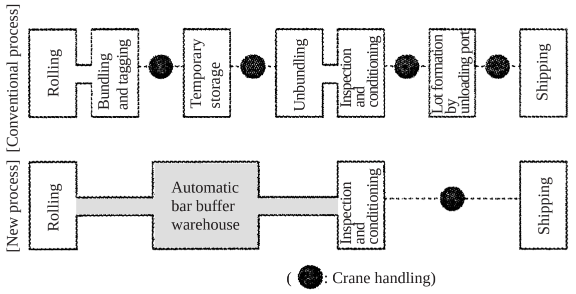


**Fig. 2 Special steel bar production process flow**

**Table 1 Main specifications of automatic bar buffer warehouse**

| | Item | Specification |
|---|---|---|
| Product | Size | Round bars: 19 - 120 mm $\phi$<br>Square bars: 42 - 90 mm |
| | Lenght | 3.5 - 8.0 m |
| Number of racks | | 2,028 |
| Unit weight | | Maximum of 4.0 t and average of 3.2 t |
| Storage capacity | | 6,490 t |
| Receiving and retrieving rate (t/h) | | Receiving rate of 150 t/h and retrieving rate of 110 t/h |

the rolling-conditioning processes was the absorption of the difference in processing speed of the rolling and the conditioning. The conditioning process runs at a low speed because steel bars are treated there one by one and for simple direct connection with the rolling process, needs to be equipped with many devices at a very high additional cost and a number of additional operators. For this reason, the direct linkage of the rolling and the conditioning processes was considered impracticable. To overcome this difficulty, we developed "a technology that can perfectly link the rolling, conditioning and shipping." This technology features the interposition of an automatic sorting warehouse, between the rolling and the conditioning processes, having a buffering function to absorb varying speed differences between the two processes. In addition, this automatic sorting warehouse has versatile receiving and delivering functions including the deliveries of products in an appropriate order for specific destinations. Thus the rolling process is successfully streamlined with the conditioning process prior to the shipping.

**Table 1** lists the specification of the automatic steel bar sorting warehouse system. As a cubic automatic warehouse, this automatic sorting warehouse has a very heavy unit weight and a very large storing capacity.

### 2.2 "Technology for completely direct linking" the rolling-conditioning-shipping processes

This technology is the fundamental technology of the automatic steel bar sorting warehouse system. The automatic sorting warehouse system has an automatic sorting warehouse where rolled and cut steel bars are transferred and stored in an unbundled state, and has inspection and conditioning lines subsequent to the automatic sorting warehouse. This system arrangement enables the free operation of the temporary bundling, tagging and temporary overhead craning of rolled bars, is free of transferring bars to the conditioning lines with overhead cranes and of unbundling after the transfer, and is free of sorting conditioned bars into specific lots for shipment to specific destinations because bars are previously sorted and fed to the conditioning lines with the order of shipments taken into account by means of the flexible delivering functions of this system (see Fig. 1). This system configuration successfully solved the most difficult problem in the complete direct linkage of the processes from rolling to delivery, that is, it absorbs the difference in the processing speeds in the processes from rolling to conditioning,

### 2.3 Loose bar storing technology

Conventionally, a set of a certain number of rolled long bars were temporarily bundled for transferring and storing as shown in **Fig. 3**. The temporary bundling practices required certain costs for temporary bundling, tagging, unbundling, and bundling and tagging materials. To eliminate the costs, we developed a loose bar handling and storing technology. This technology embodies a system configuration, as shown in **Fig. 4**, comprising a "loose steel bar transfer machine" designed to prevent bar damage during transfer, a "cassette number

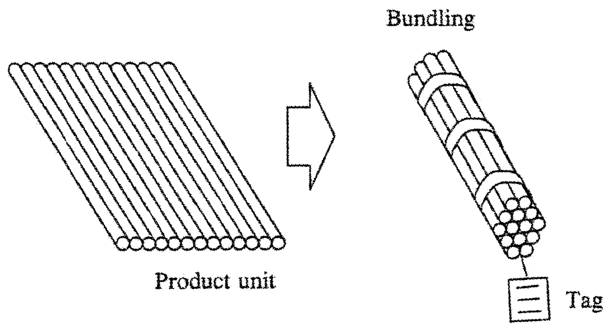


**Fig. 3 Conventional bar storing method**

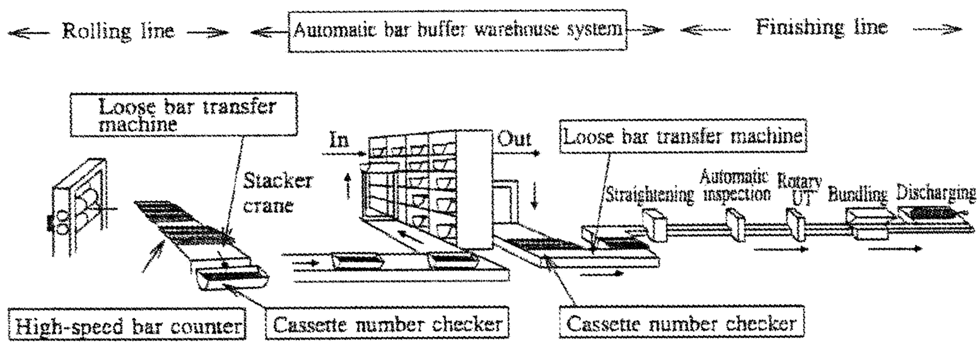


**Fig. 4 Loose bar storing technology**

checker" designed to perform automatic lot boundary control, and a "high-speed bar counter".

2.3.1 Loose bar transfer machine

Binders are needed for the transfer and storage of a number of long loose steel bars as stated above. In place of binders, we developed cassettes mountable on the loose bar transfer machine, capable of transferring loose steel bars to, and storing them in the automatic sorting warehouse (see **Fig. 5**). The problem of the use of these cassettes was the possible damage to steel bars by contacts of steel bars to the transfer machine and to the cassette when the bars are placed in and taken out of the cassettes. To eliminate the possible damage, we designed an oval form of the arms of the transfer machine such that the arm-to-arm inside width varies as the prongs of the fork lift are opened or closed (see **Fig. 6**). Arrangements were also made such that the steel bars may not contact the supports of the cassette or the supports of the bar receiver in the conditioning line as the transfer machine is raised or lowered. Thus the transfer machine can transfer loose steel bars free of damage to them during the transfer.

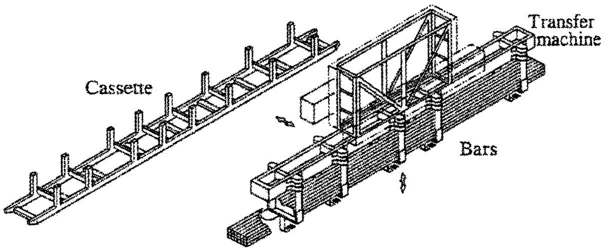


**Fig. 5 Loose bar transfer method**

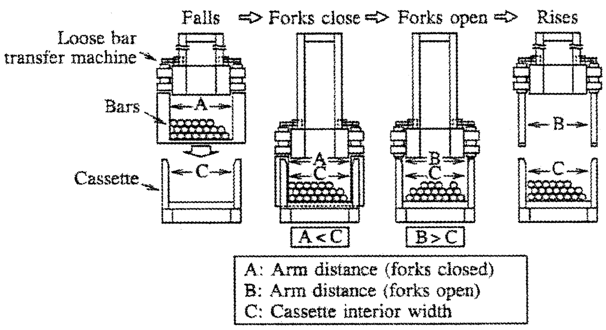


**Fig. 6 Loose bar transfer machine**

2.3.2 Cassette number checker

Another problem of the automatic bar sorting and storing was the perfect automation of bar lot boundaries. Since unbundled steel bars are not tagged, the data control of cassettes containing steel bars had to be done only by computer tracking. We developed a cassette number checker that can back up the cassette data control in the event of any tracking error. A bar code plate is attached to each cassette which has a given cassette number, and the cassette number checker automatically checks the bar code plate at the inlet and outlet of the automatic sorting warehouse as illustrated in **Fig. 7**. The bar code reading accuracy of the checker remained 100% throughout 6-month continuous operations.

2.3.3 High-speed bar counter

In addition to the above-outlined cassette data control, the control of the number of bars is also important for the precise performance of loose bar lot boundary control. Conventionally, an automatic bar counter was used that counted the number of bars by image analysis of bar ends, but its reliability was not high because bar end deformation could often cause miscounting. The bar counter we developed to replace the conventional one recognizes the shapes of bars as sketched in **Fig. 8** and has a higher detection rate, requiring less human backup.

## 3. High-Precision Surface Flaw Detector

### 3.1 Outline of product conditioning

Hot-rolled steel bars are subsequently stored in an automatic sorting warehouse, cooled, and then inspected and conditioned one by one in the automatic flaw detecting line. In the automatic flaw detecting line, warp is straightened through a two-roll straightener, internal quality is examined by a supersonic flaw detector, and surfaces are inspected by a surface flaw detector, so that only steel bars that have passed these examinations are released downstream

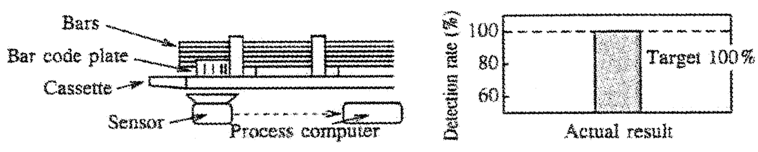


**Fig. 7 Equipment outline and detection rate of cassette number checker**

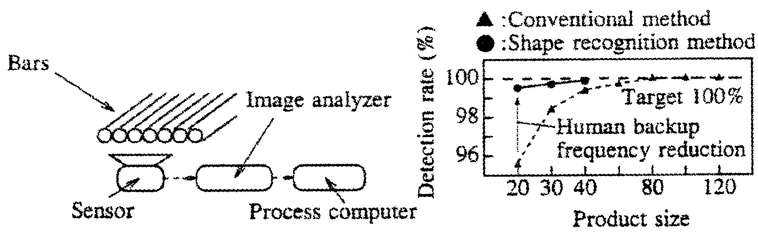


**Fig. 8 Equipment outline and detection rate of high-speed bar counter**

for bundling and delivery. (Any bar detected as having slight flaw is reconditioned and allowed to join the examination-passed bars.)

The steel bar mill at our Muroran Works has three automatic finishing lines whose specifications are as listed in **Table 2**. The three lines are selectively used depending on applicable surface flaw inspection standards, product size, and other requirements. The method of surface flaw detection at the No.1 and No.2 automatic finishing lines is magnetic leakage flux test, while that at the No.3 automatic finishing line is automatic magnaflux flaw detection. Besides, NS Bar & Wire Co. LTD has an automatic finishing line which is designed to the specifications of the No.1 automatic finishing line at Muroran Works but which has capacity-increased equipment capable of detecting flaw of products of larger sizes, and assures a higher level of flaw detection than the existing lines. The following subsections describe the features of these surface flaw detectors.

### 3.2 Magnetic leakage flaw detection

Magnetic leakage flaw detection is a method generally used for the surface flaw detection of steel bars, where they are magnetized by a yoke coil and magnetic flux leaking from surface flaw is detectable by a pickup coil (See **Fig. 9**). Both the yoke coil and the pickup coil rotate about the steel bar. If a surface flaw is detected, a marker located downstream of the detector marks the flaw for repair by an operator.

The surface flaw detection accuracy of a magnetic leakage flux testing (MLFT) machine in terms of flaw depth was conventionally 0.15 mm. If the detecting probe is made smaller to increase the proportion of a flaw area to the area of the probe, the S/N ratio (the ratio of the signal level to the noise base) of the flaw detection is improved, but the detection sensitivity (the signal level) of the probe is decreased because the probe is made smaller, and the S/N ratio of the electric noise base degrades. Thus, simply downsizing the probe cannot assure S/N improvement.

In view thereof, we improved the exciting capability by improving the material of the exciting yoke, improved the probe sensitivity by

**Table 2 Main specifications of automatic finishing lines**

| | | Surface inspection | | Product size |
|---|---|---|---|---|
| | | Type | Detectablility | |
| Nippon Steel's Muroran Works | No. 1 automatic finishing line | MLFT | Depth ≧ 0.10 mm | Bar 19 - 60 mm $\phi$ |
| | No. 2 automatic finishing line | MLFT | Depth ≧ 0.15 mm | Bar 19 - 80 mm $\phi$ |
| | No. 3 automatic finishing line | Automatic magnaflux flaw detecter | Depth ≧ 0.10 mm | Bar 40 - 120 mm $\phi$ |
| NS Bar & Wire Co., Ltd's automatic finishing line | | MLFT | Depth ≧ 0.10 mm | Bar 19 - 65 mm $\phi$ |

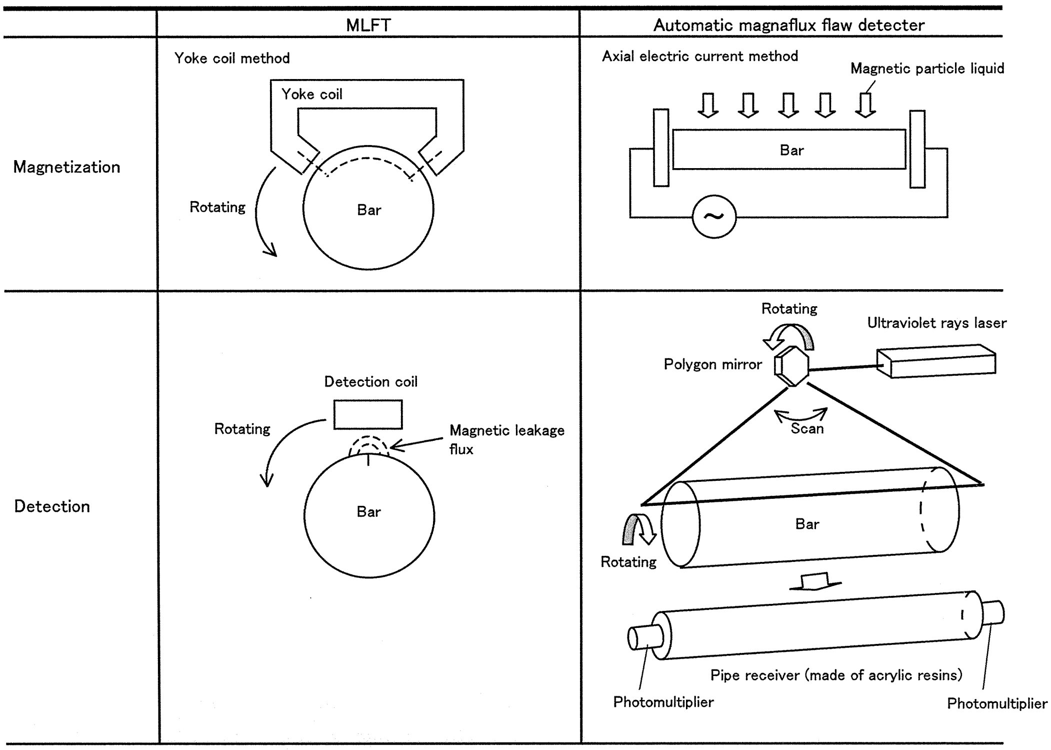


**Fig. 9 Inspection principles of MLFT and automatic magnaflux flaw detecter**

improving the material of the probe, in an attempt to override the drawback of the probe sensitivity decrease by probe downsizing, and achieved a surface flaw detection accuracy of 0.10 mm. For the material of the exciting yoke, we adopted a steel plate whose iron loss is smaller than that of the conventional yoke material, and improved its exciting capacity by reducing coil heating. As for the material of the probe, the advanced machining technology using laser permitted intricate machining and shaping and enabled the use of materials having a high magnetic permeability, to result in our successful improvement of probe sensitivity. As a consequence, we have a higher assurance level for surface flaws and we can apply our automatic inspection system even to products for which a surface flaw detection accuracy of 0.10 mm is specifically required.

### 3.3 Automatic magnaflux flaw detection

The automatic magnaflux flaw detection is a process of a unique development where an electric current is applied to the steel bar while a magnetic particle liquid is sprayed upon it by an axial current method, and magnetic particles are attracted to flaws, if any, by magnetic fluxes leaking from the flaws; thereafter, laser beam is irradiated upon the magnetic particles sticking to the flaws, and the subsequently excited, glowed and reflected light is detected by a photoconductive probe.

Fig. 9 depicts the mechanism of the flaw detection by this process. Ultraviolet rays of a spot laser are emitted through a rotating polygon mirror upon a steel bar to whose surface flaw magnetic particles are sticking. This violet ray irradiation upon the magnetic particles of the flaw excites the particles to glow, and the reflection is detected by an acrylic pipe receiver. By the photomultipliers at both ends of the pipe receiver, the light energy of the detected light is multiplied and converted to electric energy to be detected as a signal. Like in MLFT, a marker located downstream of this detector marks the flaw for repair by the operator.

The surface flaw detection accuracy of this automatic magnaflux flaw detector is 0.10 mm, same as that of MLFT. The operation time cycle of this detector is longer and its productivity is lower than that of MLFT, but it is advantageously almost free of over-detecting too small surface defects such as slight surface irregularities and can be used for automatic detection of bar surface flaws that used to be visually checked by operators. This detection, too, contributes to the improvement of surface flaw assurance level.

## 4. Conclusion

The above-stated improvements have significantly contributed to the enhancement in the quality and delivery services of steel bars supplied from our Muroran Works. By the introduction of the most advanced flaw detection lines and the same inspection assurance capacity as those of Muroran Works into NS Bar & Wire Co. LTD, we have established an efficient production system.

Meanwhile, quality requirements from customers continue to escalate, therefore we will challenge to further strengthen our quality assurance system based on these improvements.

### Reference

1) Ono, T. et al.: Shinnittetsu Giho, (358), 6 (1996)