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Synopsis :
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1 Introduction

Japan's state-of-the-art steelworks today are known for their advanced modernization and rationalization as evidenced by, for instance, their world's top-ranking labor productivity. This achievement, however, does not represent all operations within any steelworks; some are still not freed from a labor-intensive work relying on manual labor. One such example is the grinding work for finished products, and the mechanization of these processes is now being vigorously pursued in various companies to improve work environment and labor productivity.

The recent progress in steelmaking technology has improved product quality, thereby decreasing the percentage of the surface grinding requirement of finished products.

Grinding the end faces of sheet pile, that is, deburring and rounding its joints, is made for improving the fitting of sheet pile joints in the pile driving works and enhancing the handling safety.

Previously, the same task was performed by the worker in the finishing line as he used a hand grinder on each of the sheet piles. For this reason, some problems arose with regard to safety and working environment. The authors have attempted to solve these problems at the Mizushima Works since 1977, and have successfully developed an automatic deburring machine based on their original design. The machine is making a smooth operation at the wide flange beam mill.

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2 Background of Development

Since the sheet pile is cut to specified lengths by hot-sawing, hard burrs may be formed depending upon the conditions of the saw teeth. While there are a number of methods to deburr and round off the joints of sheet piles, the method adopted here involves smoothing the cut face with a grinder and rounding with a wire-brush. However, in the course of the experiment, it was found that brushing alone could provide adequate grinding effects. The developmental experiment was made in three steps. The first step comprised the fundamental experiment to study the grinding behavior of brushing wire. The second step sought a method for uniform working of the complexed geometry of sheet pile joint. Finally, the third step consisted of a process experiment to examine the feasibility of practical application from the technological and economical viewpoints.

2.1 Grinding Behavior of Brushing Wire

A single piece of wire with actual brushing portion of a few millimeters was applied at high speed to an edge of sheet pile, and its behavior was photographed with a high speed camera. The experiment revealed the following facts.

(1) Wire grinds the edge of the sheet pile as the former bends like a whip at the moment of collision with the latter.

(2) The maximum grinding effect is obtained when the wire is applied to the edge of the steel product at a right angle. If the angle is 45° or under, no grinding is possible.
(3) The brushing amount is markedly affected by material, diameter and length of the wire.
(4) Successive grinding with a multiple number of wires enhances the grinding effect through a complicated interference between wires.

2.2 Method of Uniform Working

The joint of sheet pile has a complex geometry, and brushes of various shapes have been trial-manufactured experimentally to round off the edges uniformly. However, no satisfactory results were obtained.

In the subsequent experiments, it was found that movements of brushing wires in all possible directions were essential, and the planetary movements of plural brushes were fairly effective. The experiment with a newly designed brush assembly with planetary movement provided an excellent grinding effect so that grinding with a grinder was not needed.

2.3 Process Experiment

In regard to the layout, the most economic way is to include the grinding of sheet pile edge in the finishing line. Basic requirements for realizing such a layout involve the capacity of grinding 2 000 piles successively, brushing time as short as 18 sec. per pile, and the capability of handling a few types of sheet pile of different shapes.

In order to elucidate the relationship between the grinding effect and brushing wire materials, dimensions, mounting, brush layout and velocity of planetary movement, the experimental devices were incorporated in the finishing line of a wide flange beam mill to carry out the process experiment. After repeated improvements, a grinding system to meet the requirements mentioned in the above was successfully developed.

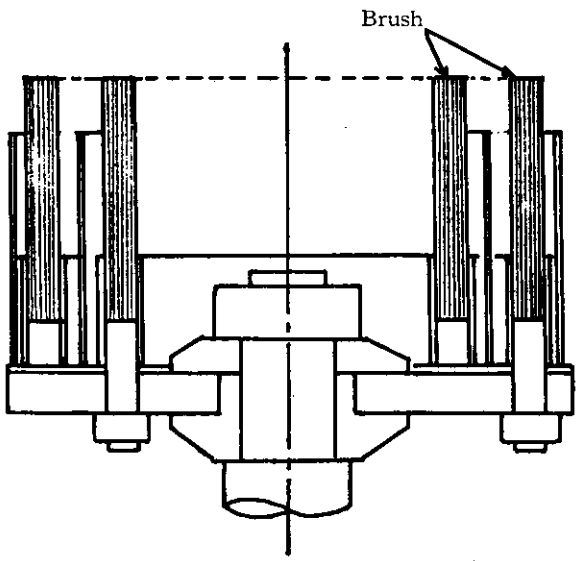

Fig. 1 Brushing unit

Table 1 Evaluation of brushing test

Brush size (mm)	Brushing amoumt (mm)	Brushing time (s)		
		5	7	10
d=1 l=60	2.5	××××	××△△	×△△△
	3.0	△△△△	○○○○	○○○○
	4.0	○○○○	○○○○	○○○○
d=1 l=70	2.5	××××	××△△	×△△△
	3.0	×△△○	△○○○	○○○○
	4.0	△○○○	○○○○	○○○○
d=1 l=80	2.5	××××	××××	×××△
	3.0	××△△	△△○○	○○○○
	4.0	△△△○	△○○○	○○○○

d: Diameter, l: Lenghth, ○: Good, △: Medium, ×: Bad

3 Technologies Developed

The characteristic technologies secured in the process of developing the present system are described below.

3.1 Brushing Unit

The brushing unit consists of 50–70 bundles of 120–180 wires each, arranged coaxially as shown in **Fig. 1**. The wire element is piano wire or hard steel wire of 0.7–1.0 mm diameter and 70–90 mm length.

The wire dimensions substantially affect the grinding effect and the service life of the brush. Using thinner and longer wires reduces the grinding effect, takes a longer time for grinding, but extends the service life of the brush. Moreover, the ground face is finished more neatly. On the other hand, if shorter wires are used to shorten the time required for grinding, the life of the brush is reduced.

Table 1 shows the relationship of wire dimensions and brushing amount to the grinding effect. The most satisfactory results are obtained with brushing amount of 3–4 mm and grinding time of 7–10 sec.

The target service life of the brush was set at 2 000 piles, based on the needs of actual process and economic requirements.

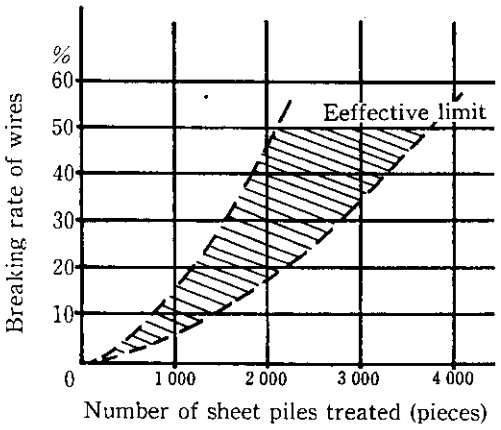

Fig. 2 Life of a brushing unit

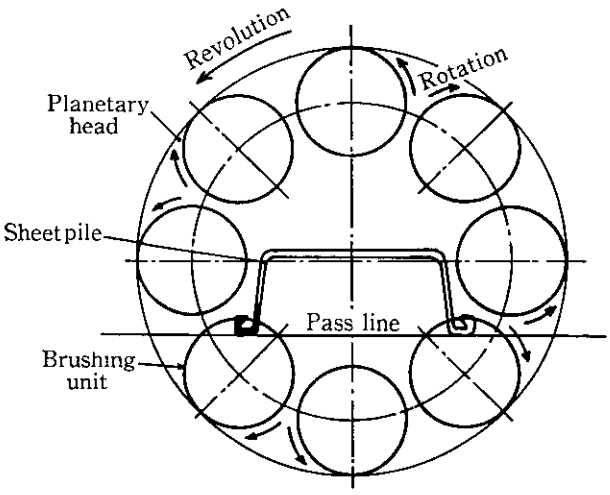

Fig. 3 Planetary head with brushing units

An example of brush life is shown in **Fig. 2**. For extending the service life, the wire dimensions and the brush layout must be selected carefully. Moreover, mounting of a back-up plate is also effective. Wires are broken at the roots and scattered away one after another as the number of piles handled increases. However, the grinding effect is hardly reduced until the number of intact wires drops to about 50% of the original one.

3.2 Grinding through Planetary Movement

In order to grind the joint of sheet pile having a complex geometry, it is necessary to put the brushes in a planetary movement so that wires will make a vertical contact with as many parts of the joint as possible. For this purpose, 8 brushes were mounted as illustrated in **Fig. 3**, and each of the brushes was rotated in an alternate direction while the whole assembly was revolved. Through such movements, brushes can grind the shaded portion of the joint, in the figure, vertically at any position, so as to ensure uniform grinding.

The higher the speed of the brush rotation, the greater the grinding effect. However, as the speed is raised, wires are bent outward under centrifugal force to reduce the grinding capability. The optimum rotating speed depends upon the wire dimensions, being 1 800–2 200 rpm for wires of 0.7–1.0 mm diameter and 70–90 mm length. Since overly fast revolution results in lopsided grinding, the maximum speed of revolution for uniform grinding is 60 rpm.

3.3 End Face Tracing Mechanism

As the sheet pile is cut by a hot saw, the cut face may be inclined as illustrated in **Fig. 4**, because of deformation of sheet pile or saw tooth at the time of cutting. In order to grind the end face of sheet pile uniformly, it is necessary that the brush face be kept parallel to the face to be ground while it is pushed uniformly. For this purpose, an end face tracing mechanism was devised.

The maximum inclination of the end face of sheet

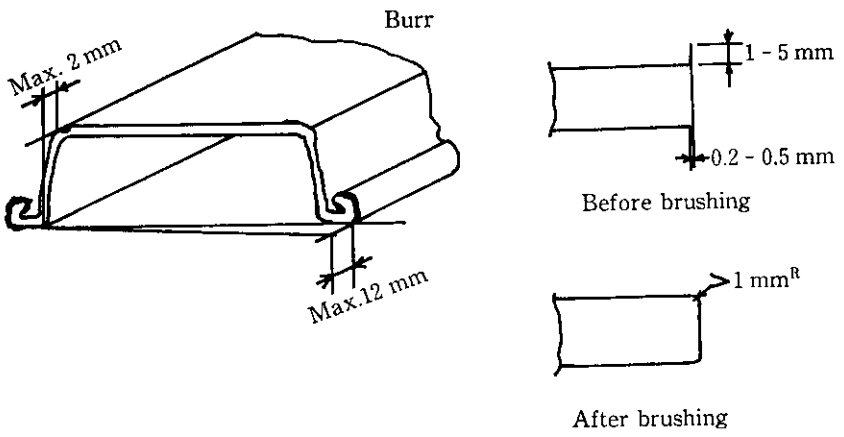

Fig. 4 End face of a sheet pile

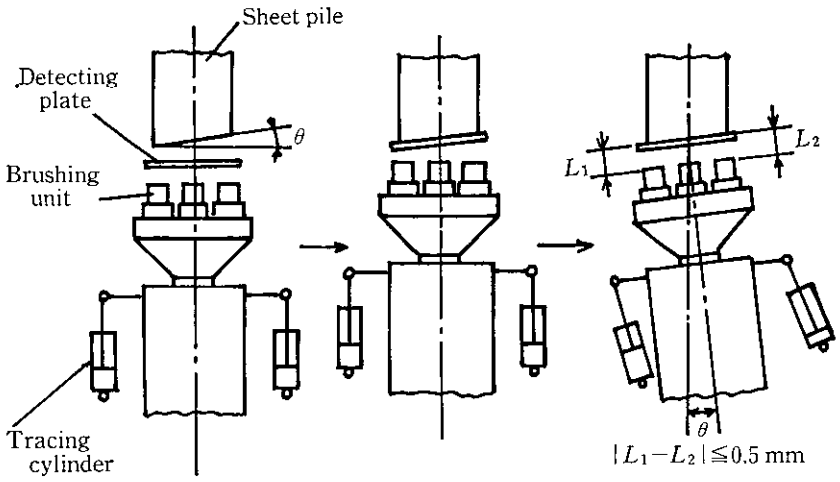

Fig. 5 Principle of tracing to end face of sheet piles

pile was 12 mm horizontally and 2 mm vertically (see **Fig. 4**). For this reason, the tracing mechanism was designed so as to be effective in the horizontal direction, and the vertical inclination was to be corrected by adjusting the actual brushing portion of the brush.

The principle of end face tracing is illustrated in **Fig. 5**. As the brushing unit is advanced, the inclination of the end face is detected by a detecting plate mounted at the fore end, and the main unit is turned by the hydraulic servo system so that the brush face is in parallel to the detecting plate. The tracing accuracy is within 0.5 mm at both ends.

4 Construction of Automatic Deburring Machine

The automatic deburring machine consists of a brushing head to put the grinding brushes into planetary movement, a tracing device to keep the grinding brush face in parallel to the sheet pile face to be ground, a brush feeder to provide specified amount of brushing under a fixed pressure, a clamper and a controller. **Fig. 6** shows a front view of the machine, indicating the locations of various components.

4.1 Brushing Head

The brushing head is provided with 8 grinding brushes as shown in **Fig. 3**. Each grinding brush is

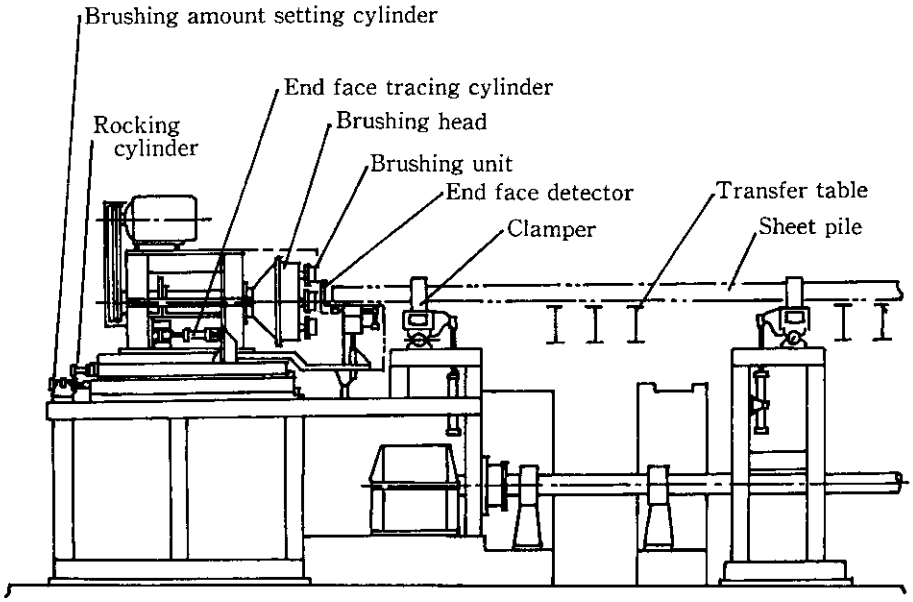

Fig. 6 Longitudinal section of deburring machine

directly coupled to gears within the head so as to rotate. The brush fixed to the gear shaft with a nut can be readily dismounted.

The drive shaft of the brushing head is of dual-structure: the inner shaft is related to the rotation of grinding brushes, and the outer shaft is hollow and is related to the revolution of the head.

4.2 Tracing Device

The detecting plate to detect the end face to be ground is mounted on the main body so that it can be raised or lowered. When detecting the end face, it is located at the uppermost end, and when brushing at the lowermost. The detecting plate is supported at its center so that it can be inclined freely. The plate is provided with two servo valves to detect the inclination. The servo valves are connected to the hydraulic circuit of the tracing cylinder, which is actuated by the signal from the servo valves so as to put the main body to linear progression or turning.

4.3 Brush Feeder

The brush feeder including the locking mechanism and the brushing portion setting mechanism is installed at the rear of the main body as shown in **Fig. 6**.

When tracing is finished the main body is fastened to the base frame by the locking cylinder, and advanced by the feeding cylinder. After the grinding brush face has come into contact with the end face to be ground, the brush head is further fed by 3–4 mm to secure the specified brushing portion.

4.4 Clamper

The clamper serves to clamp and center the sheet pile. As shown in **Fig. 6**, three clampers are provided in the longitudinal direction of the transfer table. Raising, lowering and clamping of the joint are performed by air cylinders so as to reduce the cycle time.

4.5 Controller

The controller serves to adjust the speeds of grinding brush rotation and brush head revolution and the brushing portion, as well as to control the time schedule of various components.

5 Work Process

The automatic deburring machine is installed at the machine side of the inspection table which constitutes the finishing line of the wide flange beam mill (see **Photo 1**). The grinding operation is shown in **Photo 2**. **Photo 3** shows sheet piles brushed and loaded on a wagon for shipping.

The steps of grinding work for the end face of sheet pile are described below.

(1) A sheet pile is carried to the grinding spot on the inspection table and positioned with an accuracy of ± 25 mm.
(2) The sheet pile is fixed on the table by the clamper so that it does not move during grinding.
(3) The main body of the deburring machine is advanced by the tracing cylinders located on both sides. When the detecting plate comes in contact

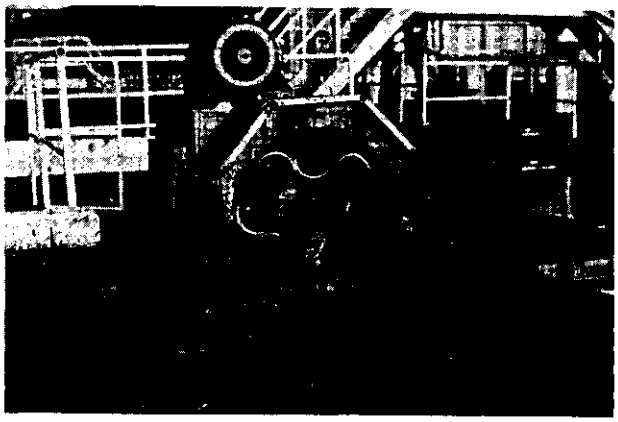

Photo 1 General view of automatic deburring machine

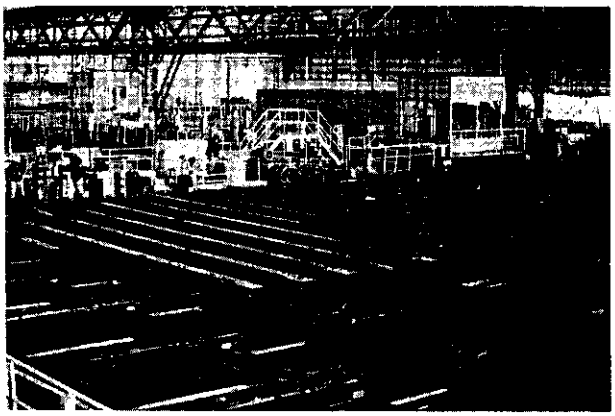

Photo 2 Sheet piles being deburred online

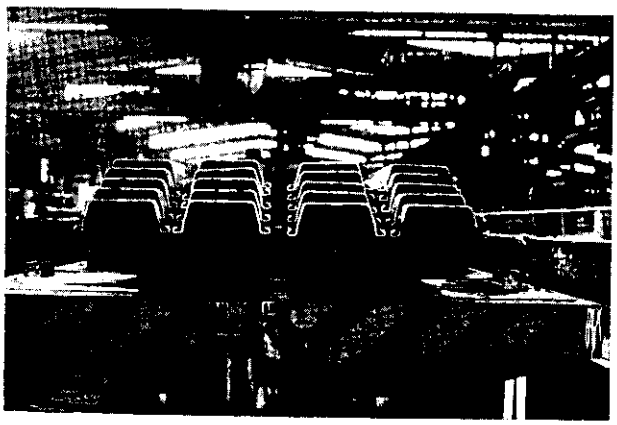

Photo 3 End surface of sheet piles after deburring

with the tip of the end face and begins to incline, the servo valve is actuated to move and turn the main body through the tracing cylinders.

(4) As two servo valves are balanced at a certain pressure, the tracing work is completed.

(5) After finishing the tracing work, the tracing plate is lowered and locking cylinder is actuated to fix the main body to the base frame.

(6) While turning the grinding brush, the main body is advanced by the feeding cylinder.

(7) The brush head is advanced quickly for a fixed distance between the grinding brush face and the detecting plate, before making a slow advance for a distance corresponding to the brushing amount of 3–4 mm. The brushing time, comprising slow advancing, stopping and withdrawing, is set to 7–10 sec.

(8) For starting withdrawing, the tracing cylinder is actuated, the locking cylinder is released and the feeding cylinder is actuated to withdraw the brush head to the rearmost end.

(9) In the course of withdrawing, the brushed sheet pile is unclamped and carried out of the brushing position.

(10) The detecting plate is raised at the rearmost withdrawal end.

6 Specifications of Automatic Deburring Machine

The specifications of the trial-manufactured machine installed in the wide flange beam mill are given below.

(1) Specifications of sheet pile
  (a) Shape
    U-type, straight type and Z-type
  (b) End face (inclination of cut face)
    12 mm max. between joints on both sides, 2 mm max. in the vertical direction.
  (c) Temperature
    Room temperature ~ 100°C

(2) Specifications of deburring machine
  (a) Type
    Planetary-movement-type grinding brush
  (b) Diameter of planetary gear head
    770 mm
  (c) Number of brushing units
    8 (4 for clockwise rotation, 4 for counter-clockwise rotation)
  (d) Brushing unit
    Material: hard steel wire or piano wire,
    Wire diameter: 0.7–1.0 mm
    Wire length: 70–90 mm
  (e) Motor
    Rotation: AC 440 V, 22 kW
    Revolution: AC 440 V, 1.5 kW
  (f) Turning speed
    Rotation: 1 800–2 200 rpm
    Revolution: 60 rpm
  (g) Clamper
    Clamping force: 2 000 kgf/unit
    Number: 2 or more
  (h) Hydraulic unit
    Pressure: 6.5×10^6 Pa
    Flow: 90 l/min

7 Features of Deburring Machine

The deburring machine has the following features.

(1) Reliable deburring
  Burrs on the joint of complex geometry can be removed completely through the end face tracing mechanism and the planetary movement of grinding brushes.

(2) Beautiful finishing
  Since not only burrs are removed, but also corners are rounded, smoother and more beautiful finish is obtained than with the conventional grinding method.

(3) Shorter working time
  The machine can be incorporated into the finishing line of steel plant to grind an end face of sheet pile in 12–18 sec.

(4) Fully automated
  The machine can be readily installed in existing steel plants, and a fully automatic, unattended operation is available in combination with the automatic carrying mechanism. Since all the steps are detected and monitored by the limit switches, any faults can be remedied easily.

8 Conclusion

An automatic deburring machine has been developed to remove burrs on the joint of sheet pile having complex cross-sectional geometry and it was confirmed that the machine can function as one of the on-line equipments. The development of this machine has resulted in significant labor saving and serves to reduce the work in unfavorable environments involving noise and vibrations.

A number of applications for patents and utility models concerning the deburring machine have been filed[2]. Moreover, it is expected that the use of this machine will be expanded so as to serve to improve the working conditions at many plants.

Finally, the authors would like to express their sincere gratitude to the personnel of Aichi Steel Works, Ltd., who extended their valuable cooperation in developing the subject machine.

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