KAWASAKI STEEL TECHNICAL REPORT
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Machine diagnosis techniques in the OCTG finishing line, especially those on the threading machine and tube upsetter, are necessary for quality control and improvement. This paper mainly describes the diagnosis logic. For the threading machine, we developed the "ratio change method" of each power spectrum according to the threading phase. For the upsetter, we developed the "pattern change method" for both upsetting force and displacement. Conventional operations will be shifted to more scientific operations by these diagnosis techniques in the OCTG finishing line.

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Development of Machine Diagnostic Apparatus for Threaders and Upsetters of Tubes*

Tadashi Okumura
Staff Manager,
Equipment of Engineering Sec.,
Chita Works

Yutaka Funyu
Staff General Manager,
Equipment & Engineering Sec.,
Chita Works

Toshihisa Taue
Staff Deputy Manager,
Seamless Pipe Technology Sec., Pipe
Dept. II, Chita Works

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Machine diagnosis techniques in the OCTG finishing line, especially those on the threading machine and tube upsetter, are necessary for quality control and improvement. This paper mainly describes the diagnosis logic. For the threading machine, we developed the "ratio change method" of each power spectrum according to the threading phase. For the upsetter, we developed the "pattern change method" for both upsetting force and displacement. Conventional operations will be shifted to more scientific operations by these diagnosis techniques in the OCTG finishing line.

1 Introduction

Technology for diagnosing problems of production machines has been drawing increasing attention as an indispensable element in attaining continuous processing in various phases of the steel industry. A continuation of hot rolling line with cold rolling line, for instance, demands an operation free from any trouble extending in several kilometers in total lengths. The conventional maintenance technology was found to be inadequate to assure and maintain a stable operation of the entire line, calling for condition-based maintenance. Some examples of this condition-based maintenance include a development of the vibration method for rotational machines to find a trend of machine deterioration for better control, and a development of machine diagnostic technology that makes prediction of machine life possible.[1]

The need of machine diagnostic technology in the steel tube finishing line, however, does not always aim at an establishment of a continuous processing line. For example, it refers to a proper diagnosing of actual conditions of toolings for threaders for forming screw-threads for joining OCTG tubings, or toolings for upsetters for hot-forging and increasing a cross-sectional area of tubing ends. It also deals with a diagnosing of possible problems of mechanical setup following tooling replacing, and a deteriorating condition of toolings following operation start. The purpose of all this is to improve levels of product quality. For this reason, machine diagnostic technology in the OCTG finishing line includes operational diagnostic technology.

This report deals with the development results of an abnormality diagnostic logic with regard to threaders and upsetters which are both most characteristic grinding and fabricating machines in the OCTG line.

2 Diagnosis of Threading Machine

2.1 Threading Machine and Contents of Diagnosis

The threading machine for OCTG is an online apparatus, which forms tube connecting threads at both ends of a steel tubing at high acouracy and high efficiency. The quality of threaded portion is specified in details by the API standard, etc. Threaded portion is subjected to visual inspection and fitting inspection and threading element inspection both using thread guages. Recently, NC threading machines are frequently used; therefore, the threading elements such as taper and lead can be automatically controlled. However, a part of the problems intrinsic to forming tools, namely, tooling must be still solved empirically. **Figure 1** shows a $3^{3}/_{8}''$ threading

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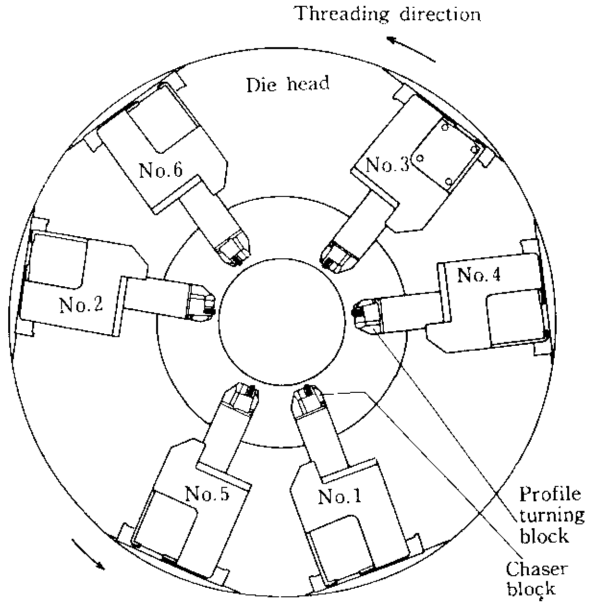


Fig. 1 Layout of tooling blocks mounted on the die head

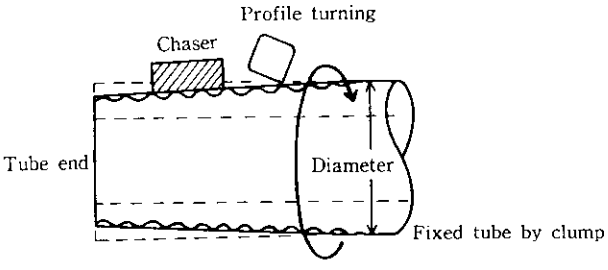


Fig. 2 Schematic condition in threading

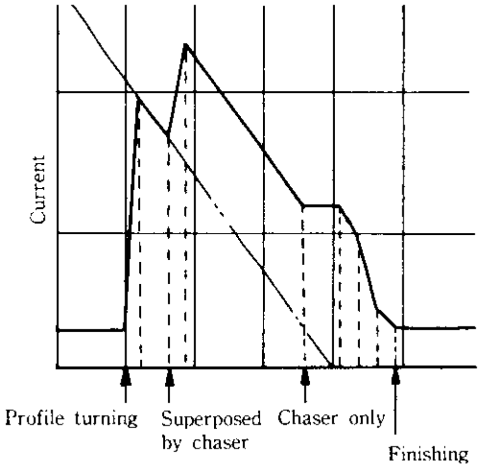


Fig. 3 Simulation pattern of threading current

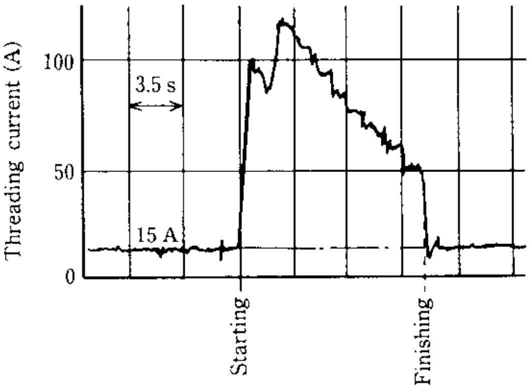


Fig. 4 An example of actual threading current

machine used in this investigation for developing diagnostic unit, with tooling blocks mounted on the die head. To Nos. 1-3 tooling blocks, chasers and profile turning apparatus are attached, and to Nos. 4-6 blocks, profile turning apparatuses are mounted. The steel tube to be threaded is fixed by chucks. When the die head rotates, the tooling blocks advance, while opening in a cone shape, so as to thread the tube. The chasers and profile turning apparatus function as follows; as shown in **Fig. 2**, at first, turning No. 1 cuts the tube end in a tapered shape, then the chaser threads the tube. Plural tools are mounted for reducing threading force per tool and improving threading efficiency markedly. Threading is carried out in nine passes, and it is not an overstatement that the last pass of chaser No. 3 determines the thread quality.

For the development of this diagnostic technology, the relations between defective thread occurring ratio and tooling malfunctioning was investigated. The defects caused by tube itself were excluded from the investigation items. Taper and lead can be diagnosed by means of the conventional magnetic linear scale, etc.

Thus the investigation was focused on the development of a technology for diagnosing tears caused by tooling malfunctioning, for which there was no established diagnostic technology.

2.2 Diagnosis by Threading Current

Since the power for threading is provided by the DC motor, the threading torque can be determined by measuring motor current. Threading torque must change by malfunctioning of any tooling. An amount cut off from the tube by chasers and turning apparatus, namely, a threading current pattern, was simulated using the values of threading elements. **Figure 3** shows a simulation result when a round thread for casing is formed on a tube with its outside diameter 139.7 mm, wall thickness 7.72 mm, and grade N80. The current pattern of actual threading is shown in **Fig. 4**.

The simulation results and the current pattern substantially coincide except the latter half of the threading process. As is clear from Fig. 3, the threading process can be roughly divided into three phases. Tooling malfunctioning would change the current pattern in the corresponding phase. In this experiment, chasers, which previously caused wrong threading, and abnormal turning apparatus, which was found by visual inspection, were prepared intentionally so as to cause defective forming results. The change of current pattern was investigated using tubes of the same lot as that used in Fig. 4. The results are as follows:

1. (1) Abnormal turning apparatus does not affect threading current. In this case, defective threading does not take place if chasers operate properly.
2. (2) Defective chasers do not affect threading current. In addition, when chaser No. 3 operates properly, defective threading does not occur.
3. (3) When chaser No. 3 operates abnormally, defective threading occurs even if the other toolings work normally.

Since plural sets of tooling share the threading force, the threading current or pattern does not change unless the whole toolings operate abnormally. According to the results shown above, it is difficult to diagnose tooling malfunctioning by means of current pattern change. However, it became clear that the threading current pattern shown in Fig. 3 can be incorporated into the diagnostic logic.

2.3 Diagnosis by Threading Vibration

Usually, the frequency characteristics of a rotational type threading machine are so distinct as at a level of 1 kHz or higher. An acceleration sensor consisting of piezo-electric element is appropriate to this band width. The sensor is tied up to the machine by screws. In order to hold the band width of frequency above 10 kHz, it is necessary to tie up the sensor with a torque more than 4 kg · m.

When the above conditions are satisfied, it is possible to make frequency analysis by threading vibrtation. In the threading machine used in this experiment, the tooling rotates and the tube is fixed; therefore, the mounting position of the sensor must be carefully selected. If the sensor is attached to the rotational tooling and an FM telemeter is used, threading vibration can be directly analysed, but, power cannot be provided to the FM telemeter continuously. Thus, the sensor was attached to the chuck, which is positioned 300 mm apart from the tube end. Consequently, threading vibration propagates in the tube over a distance of 300 mm to reach the sensor via the chuck. The propagation characteristics, i.e., frequency characteristics of threading vibration change depending on the variation of chucking force. Then, hammering test was performed, in which tube size and hardness, and chucking force were varied. As a result, it was found that tube size and hardness do not affect frequency characteristics, and that chucking oil pressure equal to or larger than 40 kg/cm^2 does not change the frequency characteristics. Therefore, in this experiment, chucking oil pressure of 45 kg/cm^2 is used.

Threading vibration, which is different from rotational machine vibration, is not continuous and occurs transitorily in every piece of tube. Therefore, all the measured acceleration data signals were stored in the data recorder and analysed.

Figure 5 shows an example of frequency analysis by FFT when round thread for casing was machined on a grade J55 steel tube of outside diameter 219.1 mm and

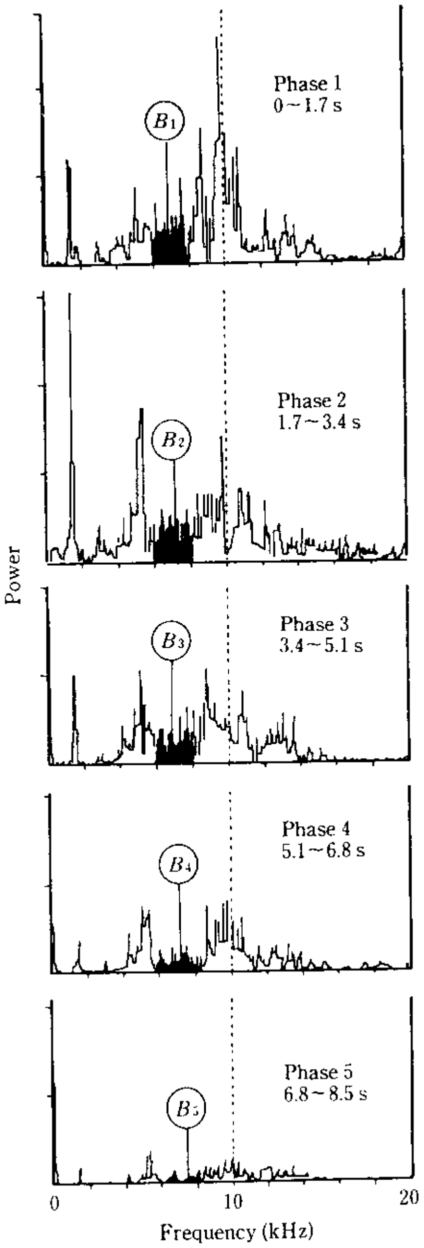


Fig. 5 Spectrum train of frequency analysis in threading

wall thickness 8.94 mm. As in the case of current pattern, the threading phases closely relate to the frequency spectra obtained by vibration analysis.

In this experiment, as in the analysis by current pattern, the frequency spectra obtained by abnormal and normal chasers were compared. The results are as follows:

(1) Regardless of tube size and grade, a frequency spectrum appropriate to diagnosis exist in band width of 6-8 kHz, shown in **Fig. 6**.

(2) In phase 3 shown in Fig. 5, the power in the above 6-8 kHz band width is different between abnormal and normal chasers.

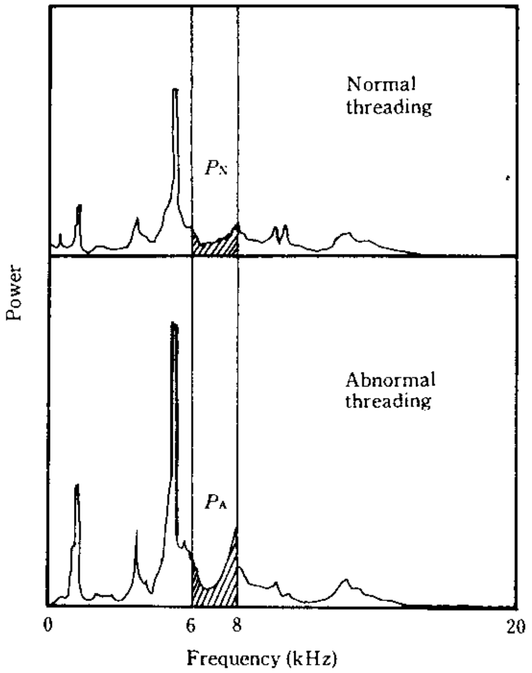


Fig. 6 Band width power increase from 6 kHz to 8 kHz at damaged chaser

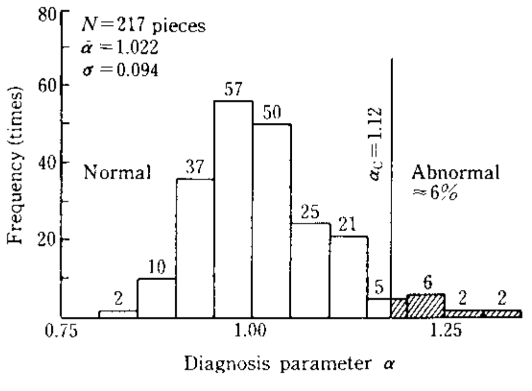


Fig. 7 Histogram of diagnosis parameter α on the normal condition of threading (API J-55 CSG 219.1 mmϕ × 8.94 mm$t$)

According to the finding described in (2), diagnostic logic can be formed as follows. A diagnostic parameter

$$\alpha = P_A/P_N$$

is defined, where P_N is the power of normal chaser in the band width shown above and P_A is that of abnormal chaser. It has been found experimentally that P_A is larger than P_N. Then the minimum value 1.12 of α obtained from experiments for all tube sizes and grades was used as criterion α_c and was applied to actual operation, with the results shown in **Fig. 7**. A chaser is diagnosed using α_c with respect to the histogram of parameter α. Since Fig. 7 is a histogram for normal chaser, about 6% of wrong diagnosis will result when using the critical value α_c obtained experimentally. In order to lower this percentage, the S/N ratio in α_c should be improved, considering the fact that vibration energy other than that of chaser threading is relatively large.

2.4 Development of Diagnostic Logic

An idea for increasing S/N of criterion α_c is that, if, from the 6-8 kHz band width power, the same band width power before the start of chaser with threading is subtracted, as shown in Fig. 3, the band width power of the vibration generated from the threading can relatively be obtained. According to this idea, the test data that determined the criterion α_c is reproduced as a new criterion parameter.

$$\beta = B_3/B_1$$

As shown in Fig. 5, B_1 and B_3 are powers in the 6-8 kHz band width as in Sec. 2.3. **Figure 8** is one of the graphs which were used for determining criterion β_c and selecting threading phase for diagnosis. It should be noted that the threading phase to be selected depends on threading rate. The criterion β_c was determined as 1.4 from Fig. 8.

From the data used in the histogram shown in Fig. 7, β values were determined as shown in **Fig. 9**. Chasers can be diagnosed by β value histogram to which the criterion β_c is applied. The wrong diagnosis percentage was decreased to 1% or lower, compared with the diagnosis using the criterion α_c.

The diagnostic logic described above is a very macroscopic method. It should be preferrable to analyze by machine dynamics using natural frequencies or rotation numbers of machine elements. However, in order to monitor operation line, the above diagnostic method will be sufficient.

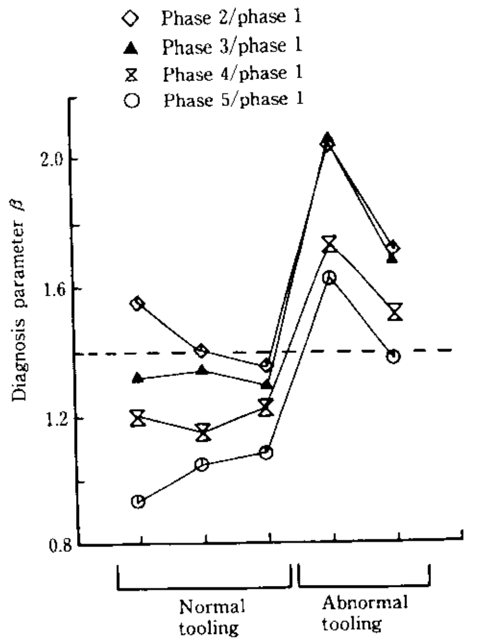


Fig. 8 Decision of diagnosis parameter β (API J-55 CSG 219.1 mmϕ × 8.94 mm*t*)

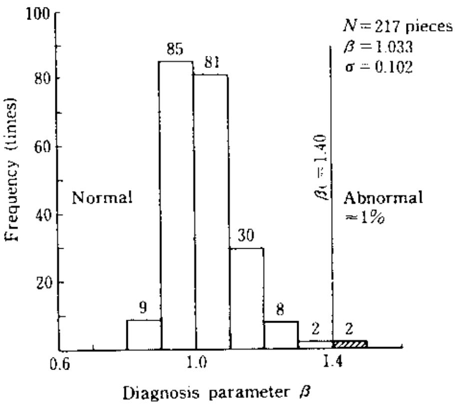


Fig. 9 Histogram of improved diagnosis parameter β on the normal condition of threading (API J-55 CSG 219.1 mmϕ × 8.94 mm*t*)

3 Diagnosis of Upsetter

3.1 Basic Structure of Upsetter and Contents of Diagnosis

The ends of tubing and drilling steel tubes for OCTG applications are formed to increase wall thicknesses. This forming, called upsetting, is made to obtain strength sufficient for threading or connecting tubes by welding or pressure welding. The wall thickening apparatus is a hot forging machine called upsetter. In **Fig. 10**, sections of upset tubes are shown. **Figure 11** indicates the basic structure of an upsetter.

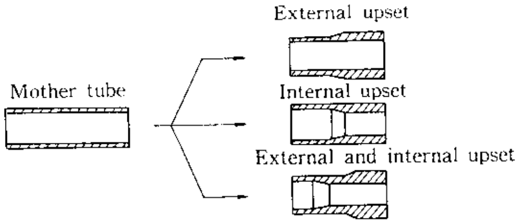


Fig. 10 Three types of upsetted ends

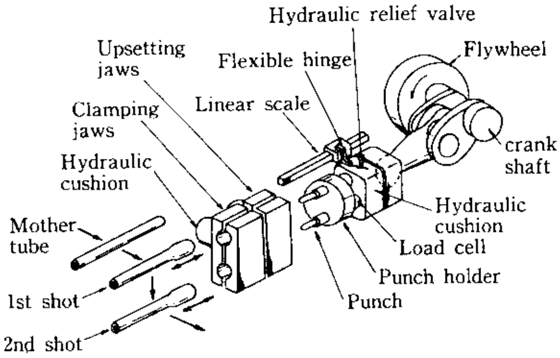


Fig. 11 General view of tube upsetter

A steel pipe that is heated to 1200°C at its one end is stopped at the predetermined position of clamping jaws. A clutch is connected between a drive motor and a flywheel to rotate a crank shaft. A punch holder mounted at the end of a rod reciprocates in a cycle of about 6 sec. Upsetting is performed at the upper dead point of the reciprocating motion. It is finished in about 0.6 sec after contact of a punch with tube end. During upsetting, the heated end of a tube is placed in dies called upsetting jaws. The unheated portion is fixed by the clamping jaws. The inner and outer surfaces of the heated end are hot-forged by punch and upsetting jaws, respectively. The hydraulic cushion of the punch holder behind the punches is important in upsetting and operation, because it has roles to accommodate excess or deficiency of upset volume caused by scattering of wall thickness and to protect the upsetter from mechanical shocks originated from wrong setting of tooling such as punch or jaws.

Upsetting force can be adjusted since an oil pressure relief value is attached to control oil pressure in the hydraulic cushion.

The function of the upsetter is as described above. However, there was no sensor available to directly monitor upsetting process; therefore, operating conditions had been discussed by conjecture. Accordingly, an apparatus was needed, which diagnoses upsetter by using combination of distance of punch movement (i.e., cushion length), upsetting load, etc.[2)]

3.2 Determination of Measuring Position

As shown in Fig. 11, the upsetter consists of only machine elements. What to be measured is load or displacement in deep part of the upsetter. In this investigation, upsetting load and punch displacement were determined to be measured, which are essential in machine diagnosis.

At first, for determination of upsetting load, it was planned that backpressure of the hydraulic cushion be measured by strain type pressure gauges which permit quick response. However, for the following reasons, load cells were to be attached between punch holder and hydraulic cushion.

(1) Since oil pressure is transmitted via cushion cylinder and tubing, delicate load change caused by tube end buckling cannot be measured by the strain type pressure gauge.
(2) Upsetting process after relief valve operation cannot be observed because of backpressure of the hydraulic cushion.

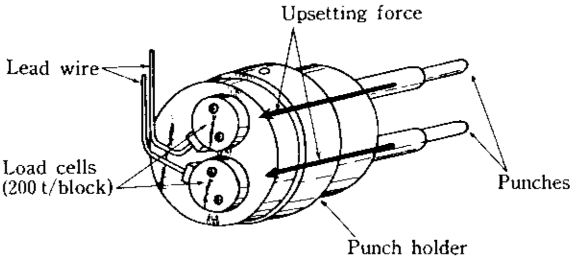


Fig. 12 General view of a pair of load cells mounted on the punch holder

Figure 12 shows the load cells attached to the punch holder. In measuring punch displacement, as in the case of upsetting load, the portion contributing to upsetting must be observed. The accuracy for measuring displacement was determined to be 0.1 mm, considering tooling precision. Response ability was determined to be 1 kHz according to upsetting time. The whole stroke of the crank was made 700 mm so that rattling of the crank shaft can be diagnosed. It is preferable to measure displacement in non-contact condition. In this case, however, considering that measurement was to be performed in an atmosphere of oil fume and water droplets caused by hot-forging, displacement of the punch holder was picked up by a hinge in a pure mechanical manner and measured by a magnetic linear scale (see Fig. 11).

The observed signals were processed by EM-1000 event memory manufactured by Kawatetsu Instruments Co., Ltd. The signals were stored every 1 ms and analyzed after the completion of upsetting. This method, although lacks in realtime quality a little, can serve the practical purpose of the diagnostic machine.

3.3 Development of Diagnosis Logic

Figure 13 shows patterns of upsetting load and punch displacement when upset tube ends were inspected and accepted. These patterns were drawn by an X-Y recorder using the observed values stored in the event memory. The product specification is API J55 EUE, in which the outside diameter and wall thickness are 73.0 mm and 5.51 mm, respectively, and hydraulic cushion pressure set value and clamping force for upsetting are 1.3 kg/cm^2 and 162 kg/cm^2, respectively. Since seamless tube was used, the mean valves of wall thickness of specimens were scattered. Therefore, cushion lengths varied. The relation between mean wall thick-

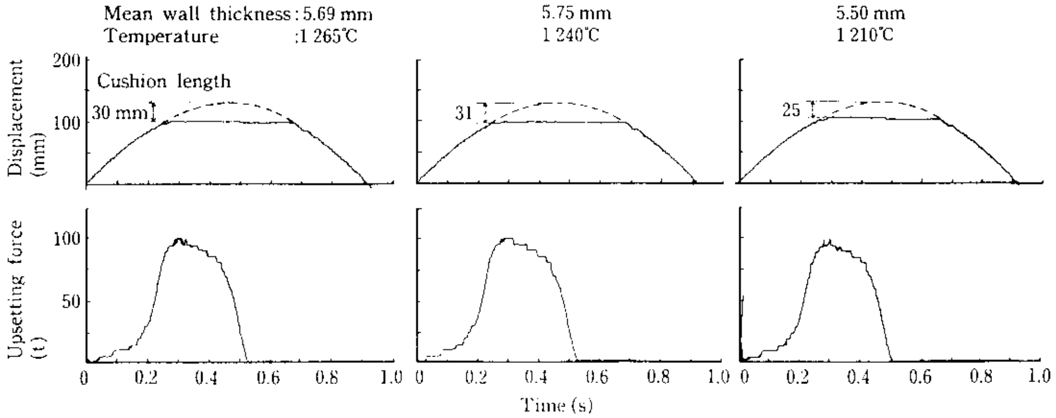


Fig. 13 Characteristic pattern of upsetting force and punch displacement after normal upsetting condition (API J-55 TBG 73.0 mmϕ × 5.51 mm$t$)

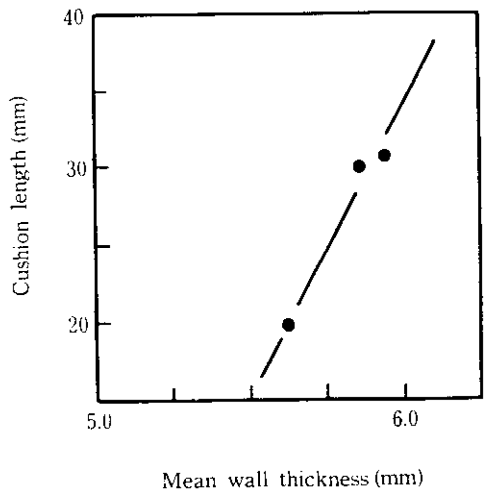


Fig. 14 Relation between mean wall thickness and cushion length

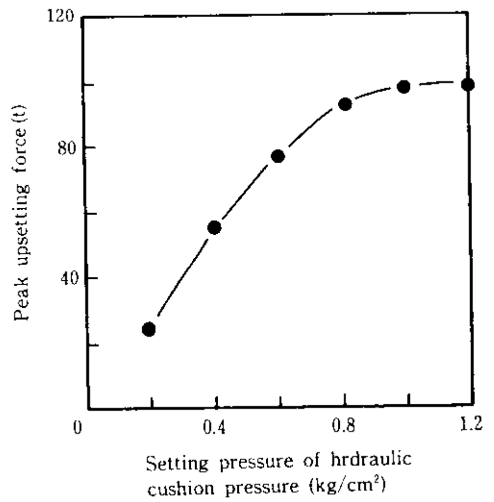


Fig. 16 Relation between hydraulic cushion pressure and peak upsetting force

ness and cushion length is shown in **Fig. 14**.

As shown in Fig. 13, when force pattern has bell shape and peak load is about 100 t, it is possible to determine mean wall thickness of tube by cushion length. The relation between load pattern and cushion shown in Fig. 13 can be used to design tooling and to improve operation.

Figure 15 shows the patterns of upsetting load and punch displacement when relief pressure of the hydraulic cushion is purposely changed. Specimens are cut from a seam-welded steel tube in which mean wall thickness varies little. Tube ends are heated to 1250°C. The upsetting specification is API N80 EUE in which the outside diameter and wall thickness are 60.3 mm and 4.83 mm, respectively. The clamping force is fixed at 162 kg/cm^2. **Figure 16** shows the relation between set values of hydraulic cushion relief pressure and peak values of upsetting force. Defective products are made in abnormal case when peak force is equal to or lower than 100 t and upsetting force pattern does not have bell shape, even if cushion length is in a normal range of 30 mm ± 15 mm. If upsetting is performed when set value of relief pressure is equal to or lower than 0.6 kg/cm^2, material is not charged between jaws and punch[3, 4], and the upset part shows undulations and inner surface depressed areas. As will be understood from the results described above, it is possible to diagnose if the relief valve of the hydraulic cushion is operated properly or not, using upsetting force pattern and cushion length.

Figure 17 shows changes of upsetting force pattern by the slipping of tube in the clamping jaws. In this case, the upsetting specification is API J55 EUE in which the outside diameter and wall thickness are 73.0 mm and 5.51 mm, respectively. The set value of relief pressure and clamping force for upsetting are 1.3 kg/cm^2 and 162 kg/cm^2, respectively. Though omitted in Fig. 11, a crank apparatus, which opens or closes the clamping and upsetting jaws, is placed at the opposite side of the hydraulic cushion. This apparatus completely closes the

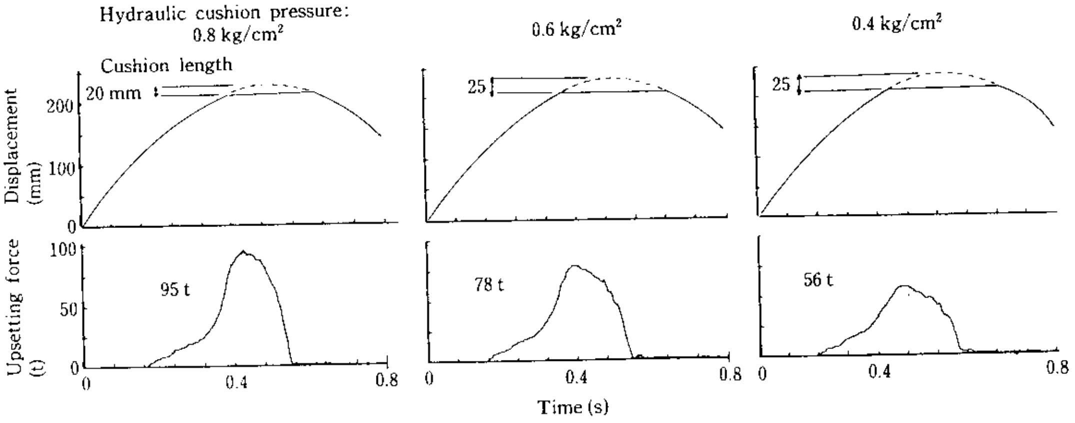


Fig. 15 Characteristic pattern of upsetting force and punch displacement by changing the hydraulic cushion pressure (API N-80 TBG 60.3 mmϕ × 4.83 mm$t$, temperature = 1250°C

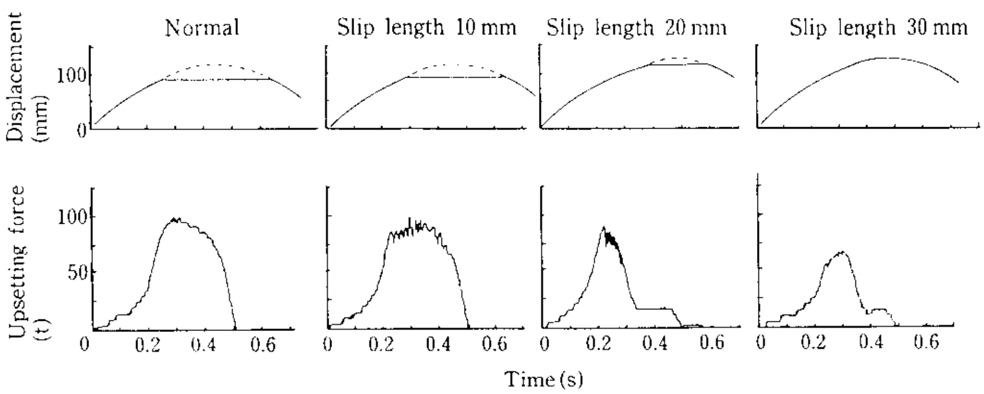
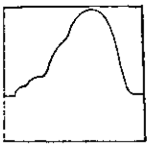


Fig. 17 Characteristic pattern of upsetting force and punch displacement by slipping of tube (API J-55 TBG 73.0 mmϕ × 5.51 mm$t$, clamping force = 162 kg/cm^2)

Table 1 Diagnosis logics of upsetter

Diagnosis item	Cushion length	Peak upsetting force	Pattern of upsetting force
Standard of diagnosis	20～40 mm	Up to 80 t	Normal pattern 
Abnormal hydraulic cushion pressure	Normal	Abnormal	Abnormal
Slipe of tube	Abnormal	Abnormal	Abnormal
Abnormal wall thickness	Abnormal	Normal	Normal

jaws when punch has come to the top dead point. Accordingly, clamping force for tube is decreased when rotation of the crank opening or closing jaws and the top dead point of the punch are not synchronized, even if the clamping force is set properly. As a result, the tube slips since it cannot resist upsetting force. The slip lengths shown in Fig. 17 were estimated from the lengths of scratches caused by slip. When cushion length is set at 30 mm and tube slips 30 mm during upsetting, the real cushion length becomes 0 mm. In addition, the upsetting force pattern and peak load will be abnormal. If slip length is 10 mm, cushion length is not changed significantly but the upsetting force markedly vibrates. In this case, it is thought that the tube slipped slowly in tiers in repetition of balance and unbalance between the clamping and upsetting forces. For a tube slipping during upsetting, there may be a case where the tube is slightly thinner than a specified outside diameter.

As will be understood from the results stated above, it is possible to diagnose whether or not a tube slipping during upsetting process has caused defective product. The diagnostic items and criterions described above are summarized in **Table 1**.

4 Conclusions

Diagnostic technology for threaders and tube upsetters, which are important forming machines in the OCTG finishing line, have been developed. The results are as follows:

(1) Even in threaders which are operated using plural pieces of tooling, the tooling can be diagnosed by combining frequency spectrum analysis and threading pattern phases.
(2) In tube upsetters, it is possible to diagnose if upsetting has been performed properly or not by combining upsetting force with pattern and peak value of punch displacement.

The newly developed diagnostic technology for operating machines should permit the transition from empirical operation to quantitative one. If knowledge engineering is introduced into the diagnostic technology in the future, automation and unmanned operation in the OCTG finishing line will be further advanced.

The authors must acknowledge the close cooperation extended by Yamatake Engineering Service Co., Ltd. in developing the diagnostic apparatus for threading machines.

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