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At Kawasaki Steel, a scientific and engineering computation system has been developed, from the earliest utilization of management science, through its applications ranging from the heat transfer analysis, structural analysis and control system to the analysis of a large scale model by supercomputer such as the fluid flow analysis. This paper describes the features of main applications which include the heat transfer analysis of blast furnace hearth, molten metal flow analysis in the continuous casting mould, stress analysis of the work roll shift mill, and simulation of hot tandem mills. The scientific and engineering computation system was developed on the basis of FACOM VP-50 supercomputer by using the corporate network. Additionally, a user supporting system which was very powerful and useful in the scientific and engineering computation was developed, and it is also summarized here.

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Scientific and Engineering Computation System at Kawasaki Steel*

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1 Introduction

Kawasaki Steel Corporation adopted systematic scientific and engineering computation practices in the process of steelworks construction and operation for the first time in 1962. Since that time, combined with the rapid improvement of computer capacity, various new analysis techniques have been introduced in the fields of factory capacity estimation, evaluation of strength of equipment, analysis of process operation, and improvement of operational techniques and facilities, contributing to the construction and improvement of various equipment and the advance of operational techniques.

In recent years, as high technology has replaced conventional practices, higher standards of quality and higher grade products have been demanded, necessitating more sophisticated computer simulation in order to achieve precise estimates and strict analyses.

This paper describes the details and characteristics of scientific and engineering computation systems at Kawasaki Steel, presenting some examples of actual scientific and engineering computation operations in the steelworks and, details the structure of the company's scientific and engineering computation system, which is centered around a newly introduced super-computer and includes a user guide system.

2 Development of Scientific and Engineering Computation Systems in the Company

Chronological changes in the company's scientific and engineering computation practices can be divided into

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Table 1 History of scientific and engineering computation at Kawasaki Steel

Phase	Main application	Methodologies of analysis
I (1962~67)	Capacity estimation of factories	· Management science · Operations research
II (1968~74)	Evaluation of strength of equipment	· Matrix method · Finite element method
III (1975~82)	Factory automation and high productivity	· Simulation for continuous systems · Modern control theory
IV (1983~)	High qualitization of products	· Nonlinear analysis · Fluid flow analysis

four main periods, as shown in **Table 1**.

In phase I, scientific and engineering computation was utilized mainly for capacity estimation of facilities. As analysis techniques, management science, and OR techniques in particular, centering around simulation, was actively used in the calculation of facility capacity balance among various shops and yards.

In phase II, nearly all facilities at Mizushima Works and Chita Works were constructed and put into operation, while the blast furnaces at Chiba Works underwent successive relining and recommissioning. During this period, the practical use of scientific and engineering computation expanded into the field of structural computation in connection with these respective facilities.

As analysis techniques, the matrix method and finite element method were adopted in the field of structural analysis and heat transfer analysis. In addition, by developing analysis programs which utilized these methods, general applicability and analysis function levels improved, contributing greatly to technical progress in facility construction.

In phase III, emphasis was placed on the continuation and automation of processes. The application of scientific and engineering computation expanded into the field of control technique analysis.

Analysis techniques included continuous system-simulation and modern control theory, permitting rolling control simulation of high-speed hot and cold rolling. These simulations, combined with improvement in the control system, resulted in the improvement of quality and yield and reduction in the heat consumption rate.

In this phase, there were also significant changes in software. Until phase II, most software was developed in-house using FORTRAN. In phase III, however, convenient and functional general-purpose software, for example NASTRAN developed by NASA (National Aeronautics and Space Administration) was introduced, marking a change from laboriously written individual programs to commercial, general-purpose software.

The change-over to commercial software freed users of scientific and engineering computation systems to devote increased time to more productive tasks such as model forming, and to challenge nonlinear problems which were yet unsolved at the time. Main aims in the present phase IV are the upgrading of products and product quality in conjunction with reductions in manufacturing costs. Improvement in facilities and operating techniques, as well as research and development, which requires high-accuracy analysis, constitute the central themes for scientific and engineering computation.

The core analysis techniques are nonlinear structural analysis, heat transfer analysis, and fluid flow analysis. The field of active application of scientific and engineering computation has expanded into the numerical analysis of non-linear phenomena, from both the aspect of facilities and operations, as exemplified by the stress analysis of rolling mill rolls and the fluid flow analysis of molten steel in the tundish of the continuous casting machine.

On the other hand, the utilization of scientific and engineering computation facilities in phase III, combined with utilization by an open system, led to an exponential increase in computer-use hours, as shown in **Fig. 1**. In addition, the size of analysis models became extremely great in phase IV, when tasks included nonlinear structural analysis, heat transfer analysis, fluid flow analysis, and combined problems involving all three. As a result, conventional business computers, because of their relatively slow operating speed, were unable to cope with analysis requests.

To satisfy such requests, a FACOM VP-50 supercomputer was introduced in March 1986 for scientific and engineering computation purposes. As a result, analysis of increased sophistication and larger scale became possible across the entire iron and steelmaking process, as well as in new project areas. The supercomputer has contributed to the improvement of efficiency in gathering new information and streamlining of experiments.

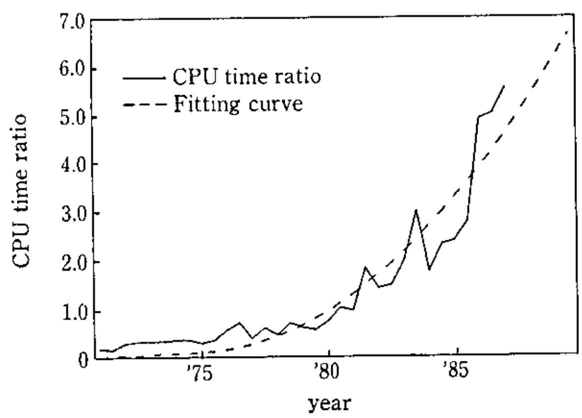

Fig. 1 Trend of CPU time ratio for scientific and engineering computation

Table 2 Application software

	External software	Internal development
Structural analysis	MARC, NASTRAN	KBSD*1, GYK series (2D FEM programs)
Heat transfer analysis	MARC	BACCAS*2, CHANCE*3, GYE series (2D FEM programs)
Fluid flow analysis	PHOENICS	NEXT-FLOW*4
Data analysis	SAS, BMDP	DAGRAS*5, GYA series (Multivariate analysis)
Simulation	GPSS, SLCS IV, CONPAK	
Mathematical programming	MPS/X	GYC series (LP programs)
AI	ESHELL, LISP	MARC-EXPERT*6
Graphics	ICAD, GSP	CAD system for piping, SGZ series (Utility subroutines for graphics)
Pre/post processor for FEM	FEMAS	GYM series (Mesh generation and plotting programs)
Guide system	PFD	Guide system for users of scientific and engineering computation

*1 Kawasaki Steel blast furnace structure design system
*2 Binding application for CAD and computation analysis of solidification
*3 Capacious heat analysis computation for engineers
*4 Numerical experimental tool for flow analysis
*5 Data acquisition and graphical analysis system
*6 MARC-EXPERT is the expert system designed to assist the preparation of MARC input data.
(The name was approved by MARC Analysis Research Corporation)

Thus scientific and engineering computation has been applied to many problems, and in the process, as shown in **Table 2**, has prompted the introduction of new techniques and general analysis technology, the development of software, and the introduction of new hardware.

3 Examples of Scientific and Engineering Computation Application

Some examples of the successful application of scientific and engineering computation are introduced below. As suggested by **Table 3**, these examples were selected to show the combinations of main iron and steelmaking processes and typical analysis techniques.

3.1 Structural Analysis of Blast Furnace Supports and Blast furnace Shell

Structural computation in the construction and repair of the blast furnace generally includes the following: (1) Framed-structure analysis based on the beam model of the blast furnace proper and its supports, as well as

Table 3 List of typical application examples

	Iron making	Steel making	Rolling
Structural analysis	Structural analysis for construction and relining of blast furnace (Ex. 1)		Stress analysis of rolls in the K-work roll shift mill (Ex. 6)
Heat transfer analysis	Estimation of refractory wear and solidified layer distribution in the blast furnace hearth and its application to the operation (Ex. 2)	Prevention of melting of cladding metal in enshroud clad ingot casting (Ex. 4)	
Fluid flow analysis	Structural design for the dust catcher of the cokes dry quenching (Ex.3)	Three dimensional analysis of molten metal flow in continuous casting mould (Ex. 5)	
Simulation			Simulation of non-steady rolling phenomena in hot tandem mills (Ex. 7)

stress analysis by the finite element method based on a blast furnace shell model, and (2) the framed-structure analysis and stress analysis of the shell in connection with the hot stove.

Because of the great size of the computation models involved, these structural computations formerly created an enormous work load in terms of the production and checking of input data such as geometrical data and load data and in the processing and evaluation of analysis results.

To solve these problems effectively and perform highly-reliable structure computation, a blast furnace structure analysis system KBSD[1)] centered around NASTRAN was developed. This system consists of several sub-systems which have the functions of creation of structure and load data, choice for extremum stress, and calculation of shell thickness. **Figures 2** and **3** are examples of the displacement of the blast furnace support frame and distribution of principal stress in the blast furnace top shell respectively, as analyzed by this system. This system was applied to structural analysis problems in the construction of No. 2 blast furnace at Baoshang in the People's Republic of China.

3.2 Analyses of Erosion of Refractories and Consolidation Layer Distribution at Blast Furnace Hearth

To extend the life of the refractories at the blast furnace hearth and control hearth condition, a continuous grasp of the status of refractory erosion and the thickness distribution of the consolidation layer is neces-

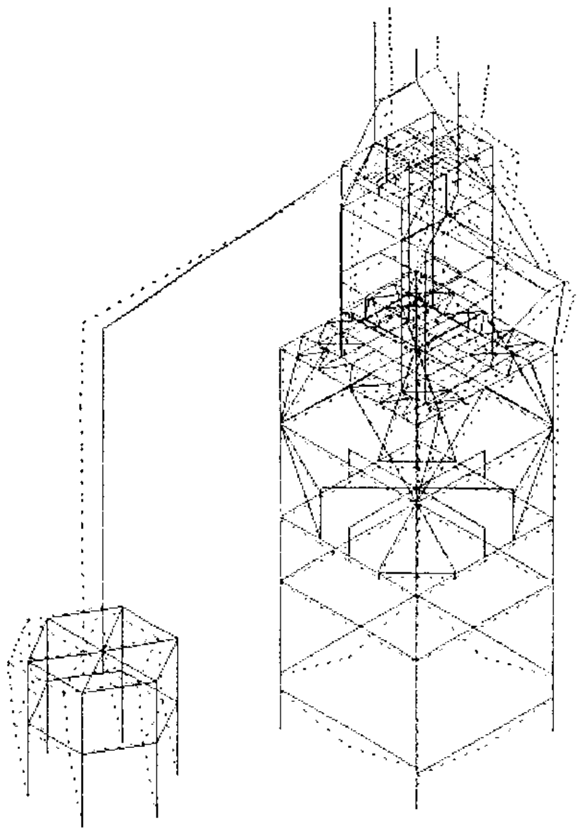

Fig. 2 Displacement analysis for the blast furnace supporting frame using Kawasaki Steel blast furnace structure design system KBSD

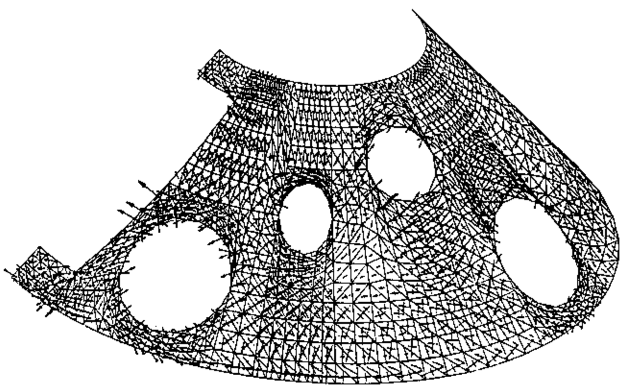

Fig. 3 Distribution of principal stress in blast furnace top shell using KBSD

sary. In the past, there were limits to the method of measuring the erosion of refractories at the hearth, and therefore, the erosion position and consolidation thickness were estimated on the basis of a combination of heat transfer analysis results and erosion measurements. In the past, one-dimensional and two-dimensional heat transfer analysis by the finite differential method and finite element method were used, but the

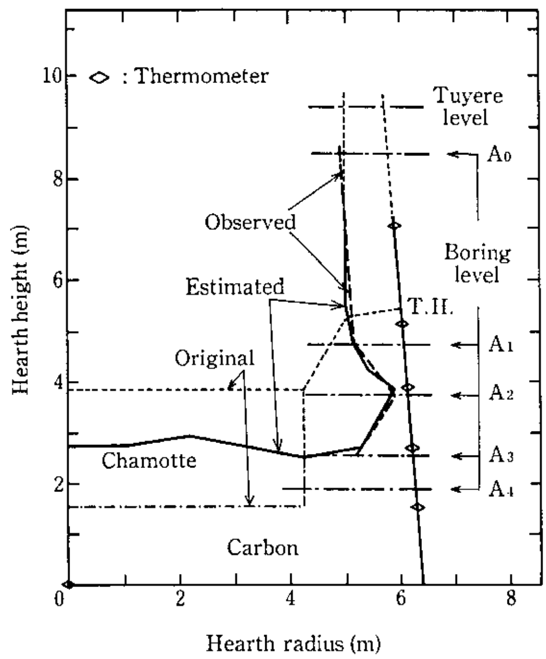

Fig. 4 Comparison of the estimated erosion line with the one measured by boring in the hearth of Mizushima No.1BF (campaign period: Apr. 1975 to Jan. 1982)

prediction of conditions at the corners of the hearth, which is of greatest import, was impossible because of the amount of time and labor required.

This example shows the development of a method for quickly and accurately estimating the refractory erosion line and consolidation layer line using the boundary element method and experimental regression analysis method, which have attracted keen attention recently, on the basis of data from plural measurement instruments buried in the hearth.[2)] **Figure** 4 shows the results of application to No. 1 blast furnace at Mizushima Works. The measured results from the hearth and the results estimated by the present method show good agreement.

As a result, it has become possible to examine the correspondence between the hearth consolidation layer and blast furnace operation, as well as the heat load from hot metal to the hearth, with benefits for furnace life extension and hearth control.

3.3 Analysis of CDQ Dust Catcher

The structure of the CDQ (coke dry quench) dust catcher was examined with the aim of improving the dust catching rate and prolonging the life of the boiler tubing against wear caused by divagation of the gas flow in the boiler tubes.

As shown in **Fig. 5**, nine modification proposals were advanced in regard to the renovation of an existing gas catcher. Simulations were performed in the respective

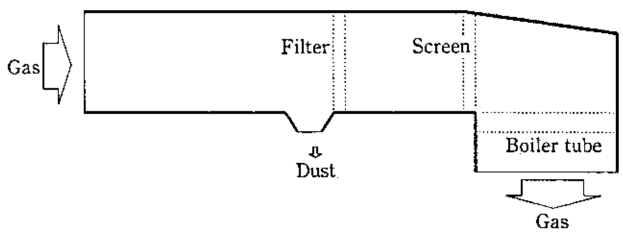

Fig. 5 Structure of CDQ dust catcher

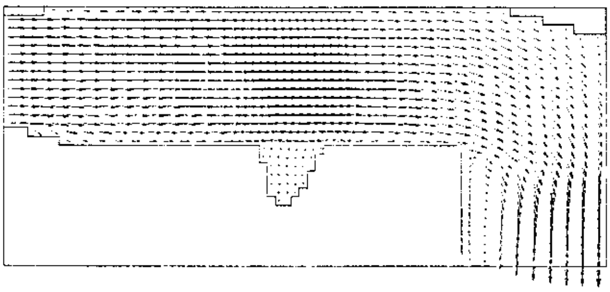

Fig. 6 Velocity distribution of gas flow obtained from a simulation model using PHOENICS

cases for gas flow and dust locus.

The calculations were made by the super-computer, using the general fluid flow analysis program "PHOENICS". In the calculation, equations for gas flow and dust locus are solved respectively. An example of the velocity vector of the gas flow is shown in **Fig. 6**.

From this figure, the degree of life extension of the boiler tube to be expected from various concentrations and velocities of dust was calculated using the divagation rate at the boiler inlet screen and boiler tube, and an overall evaluation including the modification cost was made to determine the optimum modification plan.

3.4 Heat Transfer Analysis of Stainless Clad Steel Ingot Manufactured by Enshroud Casting Method

In the enshroud casting method for the manufacture of clad steel ingots, a stainless steel plate is placed in the casting mould as a core material. Molten steel is then poured around the core material to clothe it. The melting loss of the core material, however, poses quality problems in this method. To establish melting loss prevention techniques, experiments and heat transfer analysis simulations were performed.[3] A solidification profile of the clad steel ingot obtained by heat transfer analysis is shown in **Fig. 7**.

The equi-solidification time line in the steel ingot suggests that the temperature of the core material is significantly affected by the heat of the upper portion of the molten steel and reaches its highest point at the top of the core material. The relation between the arrival temperature at the top of the core material and the core material thickness D is indicated in a graph, as shown in

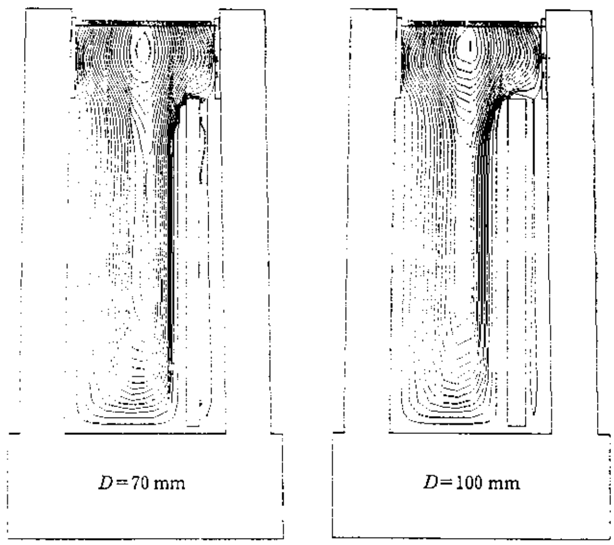

Fig. 7 Calculated solidification pattern of 23-t stainless steel ingot with varying thickness of cladding metal, D

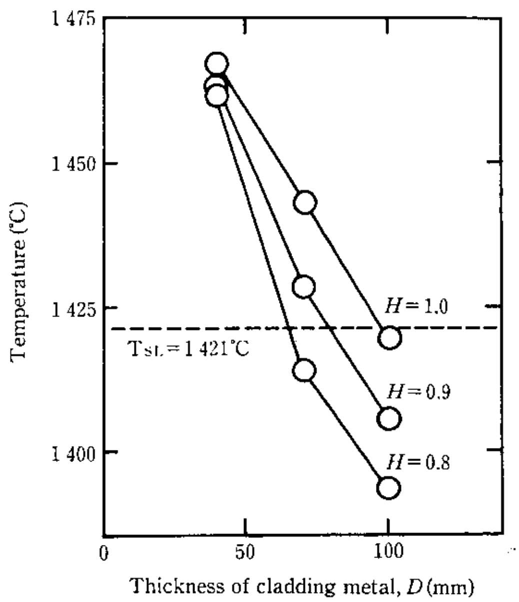

Fig. 8 Maximum temperature on the top of cladding metal

Fig. 8, after the relation is stratified by parameter H (hot top ratio of clad steel ingot/hot top ratio of Al-killed steel ingot), which relates to the top molten steel effect. As a result, it was found that the arrival temperature becomes higher as D becomes smaller and H becomes larger.

Assuming that melting loss of the core material occurs when the arrival temperature rises above the solidus line temperature, the lower-limit thickness of the core material for preventing melting loss can be determined by referring to parameter H, as shown in Fig. 8.

The melting loss in actual steel ingots and the melting loss generation conditions obtained by calculation show good agreement. The results of this analysis of non-melting loss conditions of core material have been incorporated into the operational factors used in the manufacture of clad steel ingots.

3.5 Flow Analysis of Molten Steel in CC Mould

The continuous casting machine, or CC, is a main item of equipment, by which steel slabs are continuously manufacturing by cooling steel from the molten state to solid. Molten steel is poured into the CC mould through an injection nozzle. The effect of non-metallic inclusions in the molten steel on the quality of steel products varies with the fluid state of this molten steel.

Photo 1 shows the molten steel flow in the mould, as analyzed by the three-dimensional flow analysis program for incompressible fluids,[4] NEXT-FLOW. This program has for the first time clarified the three-dimensional flow state from the injection nozzle to the mould bottom. Using a detailed flow analysis of the nozzle discharge port, the program evaluates the effects of the inverse up-flow and descent flow in the mould on product defects, and has been actively used for the modification of facilities and set-up of operating conditions.

Since this analysis involves large-scale computation, a super-computer is used and extensive vectorial tuning is carried out.

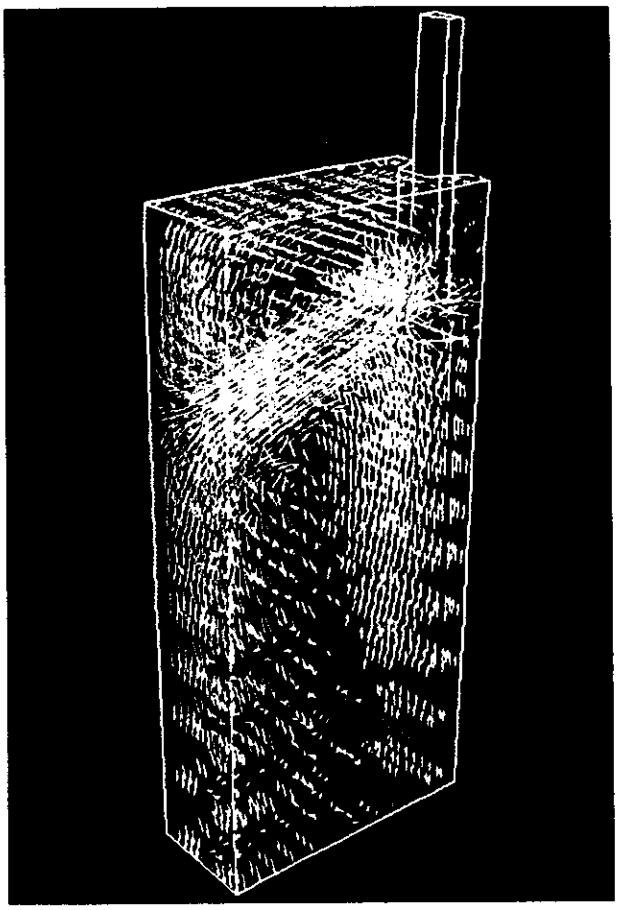

Photo 1 Bird-eye-view of velocity vector visualized from computation results

3.6 Analysis of Roll Strength in Work Roll Shift Mill

As shape and crown control mills and rolling under high pressure have come into widespread use in plate rolling and hot and cold rolling, the load on rolls has increased, leading to an increased occurrence of roll cracking accidents, a situation requiring the analysis and prediction of roll deformation and stress during rolling. In response, the company developed an analysis system for the work roll shift mill. The core of the system is the general structural analysis programs MARC and NASTRAN. These programs are now used in performing deformation and stress analyses of rolls used in the company's commercial mills.

Examples of the analysis of the increased/decreased effect of roll stress due to various combinations of parameters such as rolling width, rolling load, work-roll bender force, roll shift quantity, and work roll taper are shown in **Figs. 9** and **10**. The key factor is the magnitude of the stress values at the points where the ends of the work roll and back-up roll are in contact with the opposing roll. These analyses have been carried out as a three-dimensional contact problem using a roll analysis system built around MARC. Through the use of this system, it has become possible not only to examine the

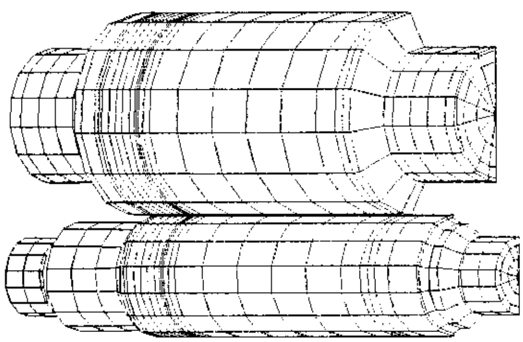

Fig. 9 Finite element model of the roll of work roll shift mill for 3 dimensional contact analysis

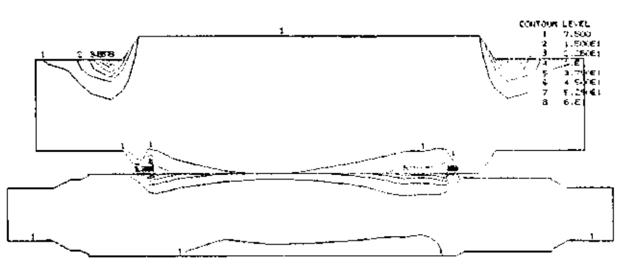

Fig. 10 Distribution of von Mises stress in the work roll and back-up roll using roll analysis system

causes of roll cracking, but also to obtain important design data for determining roll specifications and mill specifications for new facilities.

3.7 Simulation of Non-Steady Phenomena in Hot Tandem Mill

The operation of the hot tandem mill requires various control systems for strip thickness, especially at the strip ends, strip thickness changes during rolling, and looper control for minimizing the variations in tension between stands. To examine these control requirements, it is necessary to know the details of strip thickness on entry to and exit from the respective various stands, with reference to external disturbances, rolling loads, rolling temperatures, rolling torque and inter-stand tension, peripheral speed of rolls, roll opening, and the aging of looper angles.

Some results of analyses of the numerical rolling model, control system model, and plate-thickness control model using the continuous-system simulation language are shown in **Figs. 11** and **12**, which indicate changes due to aging in plate thickness, as well as the rolling loads at various stands.[5,6] The quantitative values of these changes and the aging values shown in these figures indicate good agreement with measured values, permitting strict analyses of non-steady rolling phenomena without the need to use commercial equipment for experimental purposes. These models have been applied to the design of control systems for the hot tandem mills at Mizushima and Chiba Works, realizing the manufacture of high-quality thin steel sheets and significantly contributing to the enhancement of quality as well as yield.

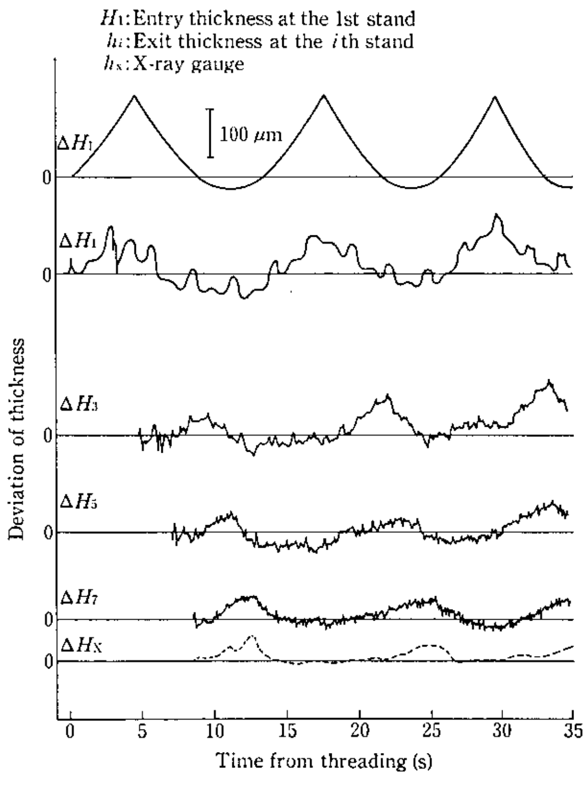

Fig. 11 Thickness changes at each stand resulted from simulation of non-steady rolling phenomena in hot tandem mills

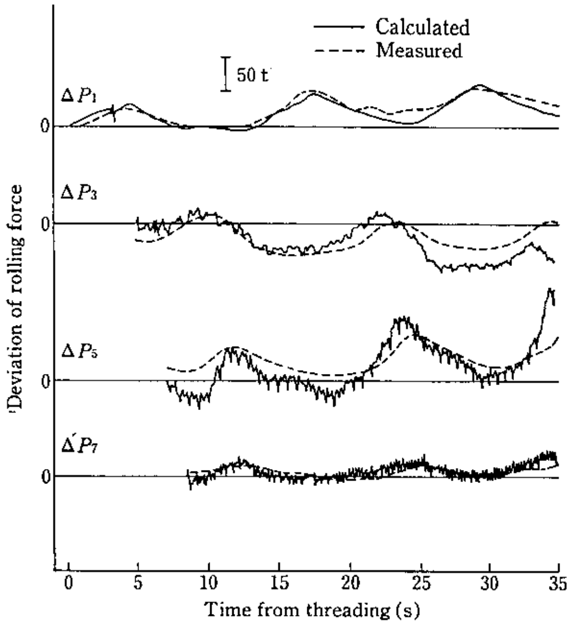

Fig. 12 Comparison of calculated rolling force changes at each stands with measured ones

4 Scientific and Engineering Computation Support System

4.1 Composition of Computer System

Scientific and engineering computation, including computer simulation, is expected to shorten research and development times and reduce costs. To meet this requirement, the company introduced a super-computer which can execute highly-advanced scientific and engineering computations efficiently and at high speed for exclusive use in scientific and engineering computations, to be used commonly by the entire company. The company is also grappling with the problem of corporate information exchange and the other works' and Head Office's common tasks involving computer utilization, including the effective use of models in scientific and engineering computation.

In the present system, the super-computer installed at Chiba Works is stand-alone type in which scalar and vector jobs are mixed, and is set up to allow use by all the company locations via the corporate network. The configuration of the computer system is shown in **Fig. 13**. Chiba Works, the Technical Research Division

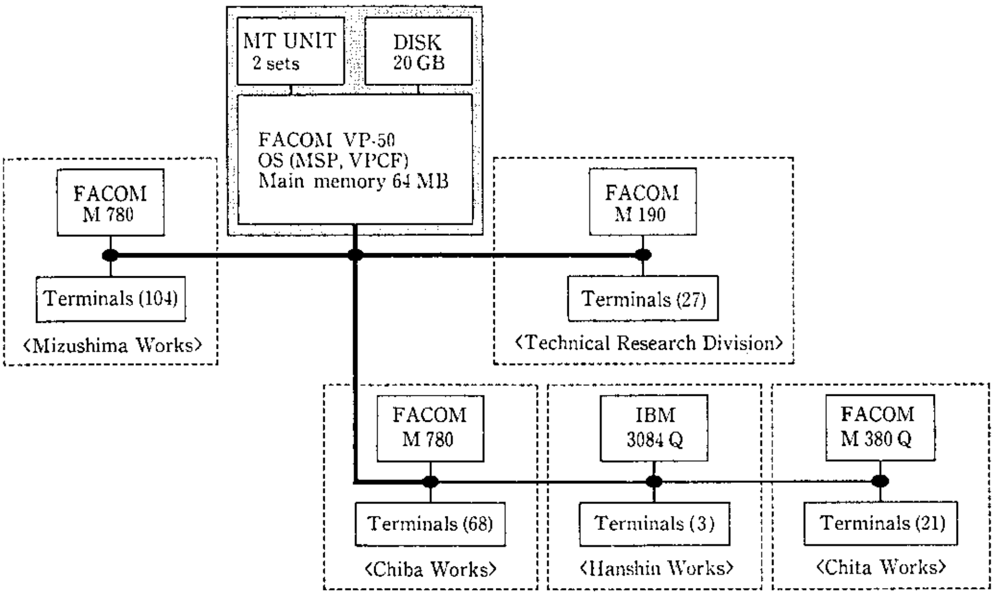

Fig. 13 Computer system for scientific and engineering computation by using the corporate network

at Chiba Works, and Mizushima Works are connected by a 48-Kbps exclusive-use network. Results of batch job execution are transmitted to the printers of various plants using transmission tools.

The operation mode of the system is, in principle, "non-stop 24 hours-a-day." During daytime, TSS and short-term batch jobs are given high priority, while long-hour batch jobs and back-up jobs are executed at night. Operation automation tools and the schedule control system, the latter developed by the company, are used as part of an effort to develop an automated computer-operation system.

4.2 User Guide System

The purpose of this system is to create an environment which will permit technical staff engaged in daily operation improvement, technical improvement, and research and development to grapple efficiently with scientific and engineering computation problems.[7] Major aims of the system are stated as "to enable even novices to easily carry out highly-advanced scientific and engineering computation" and "to allow to quickly transmit to a large number of person various types of up-to-date information such as the system stop and system improvement items." The construction of the system is also aimed at relieving the burden of public announcements accompanying an increased number of users.

The functions of the system for implementing these aims are:

(1) Functions for the support of the execution of all general-purpose software in the system.
(2) Ample assist functions when entry mistakes are made or usage is unclear.

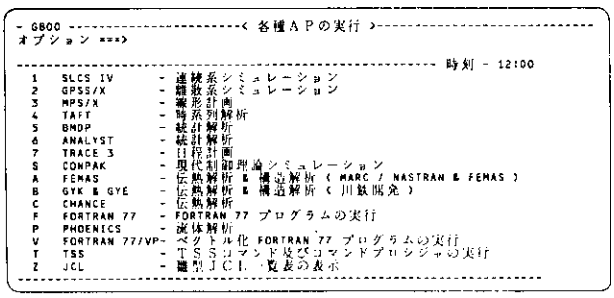

Fig. 14 An example of menu for application packages

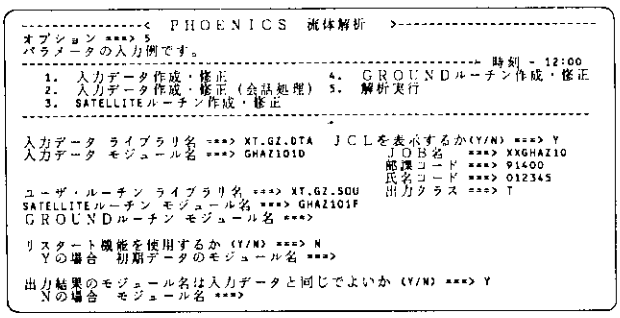

Fig. 15 Execution guidance for PHOENICS

(3) Display of the utilization manual, which is useful at the time of menu selection.
(4) Functions whereby the user can control data and programs.
(5) Information function regarding the introduction of new software, etc.

Portions of the conversational-type menus are shown in **Figs. 14** and **15**.

With this system, peripheral knowledge, such as the job control language necessary for performing scientific and engineering computation, is no longer needed. Further, the fields supported and types of application software have become varied and complicated, but enquiries from users and utilization assistance can be effectively processed.

Types of scientific and engineering computation application software include structural analysis, heat transfer analysis, fluid flow analysis, consultation systems MARC-EXPERT utilizing AI, and the others shown in Table 2.

5 Future Prospects

In the past, scientific and engineering computation introduced new numerical analysis methods to satisfy the analytic needs of the times and endeavored to expand the fields of application.

From the aspect of hardware, every effort was made to introduce the latest equipment, including conversational-type terminals and the supercomputer.

As a result, the volume of CPU use has nearly doubled in three years, and utilization of scientific and engineering computation systems has been steadily increasing. To meet these needs, it is necessary to continue the introduction of new analysis methods and the installation of hardware in the future, as in the past.

In particular, the following three points are being treated as urgent problems:

(1) Expansion of Scientific and Engineering Computation Users
The number of users of scientific and engineering computation systems at present accounts for about 30% of all engineers. In the future, scientific and engineering computation will be essential to facility improvement and operation technique improvement, as well as to research and development. The number of scientific and engineering computation users will increase as a result of both the upgrading of support systems and the education of engineers.

(2) Establishment of Visualization Techniques for Analysis Results
At the moment, graphic representation of numerical analysis results is limited to static display, which is inadequate for expressing the results of heat transfer analysis, structural analysis, and fluid flow analysis, slowing the evaluation process. In the future, visualization techniques for numerical analysis results, such as computer animation, will be established to further improve efficiency in research and development.

(3) Model Construction of Empirical Techniques
Past objects of scientific and engineering computation were mostly phenomena which could be described in quantitative models. In the steel works, however, many events cannot be adequately rendered in quantitative form, and decisions are based on experience. In the future, when operational techniques are to be improved, it will be necessary to base models on experience. The technology for this includes AI and fuzzy logic.

6 Conclusions

This report has described the features of scientific and engineering computation systems at Kawasaki Steel. The main points are as follows:

(1) In the process of the construction, operation, and research and development related to its steelworks, the company has consistently adopted new methods, new software, and new hardware.
(2) As shown in typical examples, scientific and engineering computation has been applied to the iron- and steel-making process, which covers extremely wide object fields and requires highly advanced analytical techniques, with excellent practical and heuristic results.
(3) Ahead of other companies, Kawasaki Steel introduced the super-computer and constructed a company-wide scientific and engineering computation system which makes use of a corporate network.
(4) The company has developed an efficient, user-friendly scientific and engineering computation user guide system which covers all needs of system users.

As can be clearly seen from the fact the first computer was produced for the purpose of scientific and engineering computation, this type of computation has been a continual aim of scientists and engineers since the advent of the computer, and will remain a powerful tool in the future. As long as innovation in iron and steel technology continues, the company's scientific and engineering computation must continue to challenge the limits of this field.

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