Increasing of Efficiency in Examination of Productivity in Assembly with Virtual Reality Software

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Since large-sized presses are manufactured to order, the field assembly work is largely affected by the condition of each customer's site. Accordingly, we try to examine the optimum assembly procedure in advance, if possible. Setting of the optimum assembly procedure is one of the most important subjects for shortening of the manufacturing lead time and reducing cost. As a means to grasp problems visually to find out the optimum procedure, Washington State University developed virtual assembly application software named VADE (Virtual Assembly Design Environment). I developed and studied a tool for the simulation of crane work, assembly, and disassembly of large-sized parts on the basis of the VADE software in cooperation with Washington State University. I will introduce this tool in this paper.

Key words: *Virtual Reality Software, Large-sized Press, Virtual Assembly Design Environment*

1. Introduction

As request for shortening of the manufacturing lead time and reduction of the manufacturing cost of large-sized presses has become more severe recently, the Industrial Machinery Division has been executing a divisional project of shortening the manufacturing lead time and reducing the manufacturing cost. The whole manufacturing process of each press is roughly divided into sales activity, receiving of an order, design, manufacture (sub-assembly), field installation (whole assembly), and delivery with inspection. The departments in charge of these processes have made targets and promoted improving activities. As a result, the total lead time has been shortened and the cost has been reduced. Among these processes, the field installation process is the most difficult to improve, which we must continue to improve. The reason for the difficulty is that the installing condition largely depends on each customer's factory and its location and the using condition of the facilities (overhead crane, etc.) and installation of each press must be simulated and special technologies are required. Accordingly, the engineers limited in number are required to work a long time on this. To continue improving activities and obtain good results, we need a device with which everyone can see problems easily and visually and find out the means to solve such problems. If we can simulate the actual assembly procedure in a virtual space by using virtual assembly software, we can obtain accurate results which everyone can understand, compared to the results obtained by the classic means which uses paper and requires special technologies. As a result of research, we found that the concept of the VADE (Virtual Assembly Design Environment) developed by Washington State University matched to our purpose. Then, we started to develop an assembly simulation tool for large-sized parts to be assembled by crane in cooperation with Washington State University. In this paper, I report the basic part of this tool which we have developed.

2. Outline of VADE

The VADE (Virtual Assembly Design Environment) is application software which Washington State University (USA) and NIST (National Institute Standard and Technology) (USA) developed in cooperation with each other. The outline of this software is as follows.

The operator puts on the head mounting display (hereinafter, referred to as the HMD) (**Fig. 1**) and the right cyber glove which has strain gauges in it (**Fig. 2**). Radio wave sensors to sense the position are installed to the operator's head and right wrist. During simulation, information is obtained from those sensors in real time. The operator wearing the HMD can see the 3-dimensional virtual space set in advance, move around the virtual space freely, and operate the virtual hand. The models to be simulated are made on a 3D-CAD system in advance and converted into special files so that the VADE can use them. The operator can pick up and assemble those models with the virtual hand (**Fig. 3**).

The VADE was developed to be used for virtual training, examination of ease of assembly, etc. by means of simulation. The final purpose of use of the VADE is to feed back the examination result of ease of assembly to the development department (**Fig. 4**).

Fig. 1 Head mounting display

Fig. 2 Cyber glove

Fig. 3 Operation of VADE

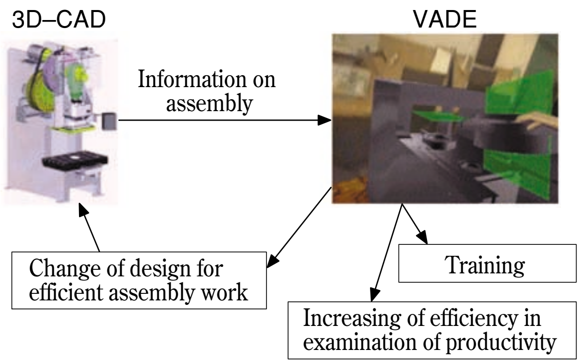

Fig. 4 Using diagram of VADE software

The main functions of the VADE are as follows.

① If the operator picks up parts, the matching condition of those parts set on the CAD system is shown visually and the operator can see which faces of those parts to mate each other (**Fig. 5**).

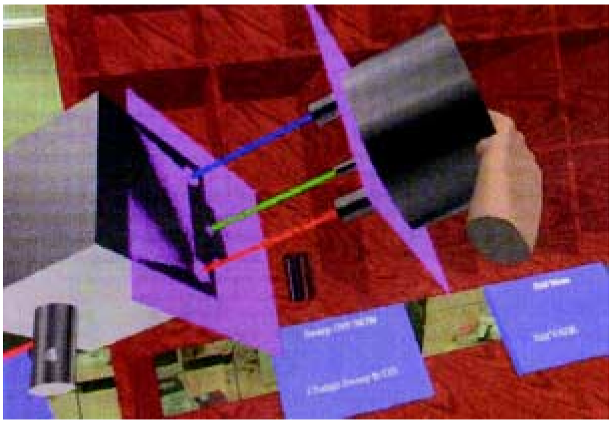

Fig. 5 Display of matching condition
Matching condition of one face and three axes set on CAD system is displayed.

② The VADE can check for interference and the operator can see interference between parts, between parts and housing, or between parts and tools.
③ The VADE can display the loci of the moved parts (**Fig. 6**).
④ The operator can change the dimensions and shapes of the parts to examine ease of assembly during simulation. Since the changed shapes can be reflected in the 3-dimensional models, those models can be corrected to solve problems.

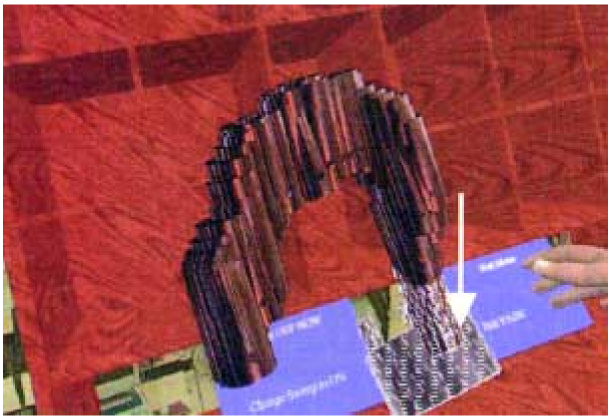

Fig. 6 Loci of movement and check of interference
Loci of movement of shaft are displayed and range where shaft interferes with block is highlighted in mesh pattern.

3. Required new functions of VADE

When we started the joint study, we specified the necessary functions by using the VADE and a model of a large-sized press as trial. The following are the functional problems detected at this time.

① Parts can be assembled but sub-assemblies could not be assembled.
② Since the model tree made on the 3D-CAD system does not match the assembly procedure and could not be changed properly on the VADE, assembly work could not be simulated.
③ Dynamic work such as transportation with jig or crane could not be simulated.
④ The range of the sensing devices is limited and work in a wide space could not be simulated.
⑤ A third person could not see the operator simulating the assembly work to grasp problems. (Observation of contents of the work by time study is assumed.)

We started with the above subjects and determined to add the following functions to the VADE.

① Simulate assembly work in proper order.
② Simulate handling of large-sized parts with crane and jig.
③ Eliminate limits of moving range of operator's eyes.
④ Observe simulating condition at free angles from remote places.

3.1 Outline of added functions

We attained some of the above functions satisfactorily.

① The model tree, or the sequence, can now be changed freely with additional systems out of the VADE.
② The crane function and push-button operation panel have now been added for simulation of crane work.
③ Parts carried by crane can now be handled with the virtual hand. (For example, the operator can push a suspended part to change its direction.)

As a result, the VADE has the minimum functions of simulating transportation and assembly of parts with a crane.

3.2 Added functions

(1) Development of tool to change model tree

Since the tool to change the model tree was developed, we were able to install a sequence changed for the assembly procedure to the VADE. Generally, the structure tree is not made according to the sequence intended by the manufacturing department. It is rather often made up as an assembly of parts which have similar functions and can be controlled easily by the design department. Accordingly, the design BOM does not basically match to the manufacturing BOM. The VADE before we installed the new functions (hereinafter, referred to as the BASE-VADE) did not have any data about this problem. That is, in the BASE-VADE, the first part of the model tree was used as the base part and the other parts were installed to it in order. The BASE-VADE did not have specification for installing sub-assemblies, either, and the operator was only allowed to install the parts in order. To assemble the parts in this way is actually very rare. In general, the parts are assembled into sub-assemblies in advance, then those sub-assemblies are installed. The first task in the joint study was to solve these problems so that the operator would be able to simulate the assembly work according to the sequence intended by the manufacturing engineers.

As a result of development, the following items became possible.

① The user can change the model tree to a sequence based on the assembly procedure freely. By moving the part that appears first in the assembly procedure to the top of the model tree, the user can see that part first at the start of simulation. By setting the necessary parts in order on the model tree, the user can appoint their assembly order.
② The user can set the sub-assemblies freely and can simulate their assembly.

(2) Crane function

With the added crane function, the following items became possible.

① Change of shape of crane on 3D-CAD system and conversion of data for VADE by user

Since the shape of the crane is different from a customer to another, a new model is required for each simulation. A detailed model can be made with a 3D-CAD system and installed to the VADE.

② Setting of degree of freedom of crane

The crane used in the VADE is divided into the bridge, trolley, and hook similarly to the actual crane as shown in **Fig. 7**. The crane body can move east, west, south, and north and the hook can move up and down. As shown in **Fig. 8**, the hook can rotate freely around the axis perpendicular to the ground.

③ Setting of moving speed of crane

The fixed moving speeds of each crane and its hook can be set in the VADE.

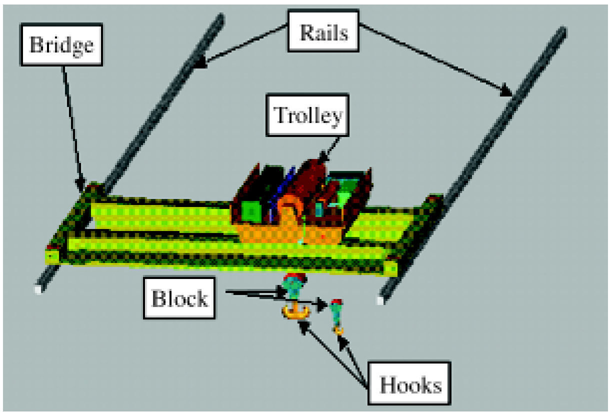

Fig. 7 Crane model

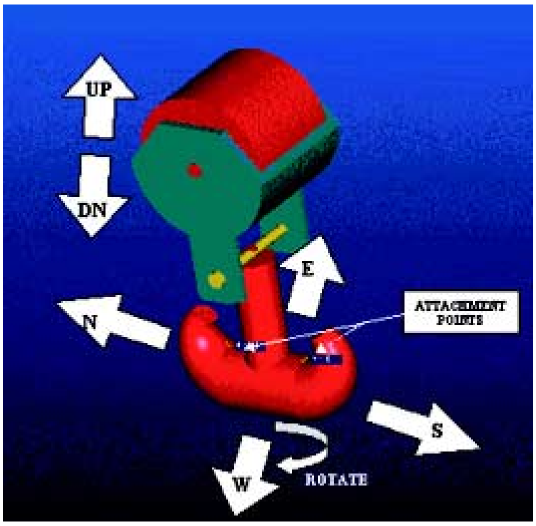

Fig. 8 Crane hook

④ Limit of crane movement

The moving range of each crane can be limited. If it is not limited, the crane keeps moving to out of its housing.

⑤ Setting of hanging fulcrum

The hanging point of each part on the hook can be set. The part moves around that point (swings).

(3) Push-button operation panel

To use the added crane function, the crane must be operated. In the actual assembly place, the operator operates the crane with its pendant operation panel, wireless operation panel, etc. Since it was impossible to hang an operation panel on the crane, we decided to simulate the wireless operation panel.

The operator operates the push-button panel installed to his (her) waist belt to move the crane or change his (her) point of view. As shown in **Fig. 9**, the operation panel consists of eight push buttons and two toggle switches. Among the eight push buttons, four are used to move the crane east, west, south, and north. The moving command is output continuously while any of these buttons is pressed. The other four buttons are used to move the hook up and down. One toggle switch is used to select the crane moving mode or operator's eye moving mode. The other toggle switch is used to select the moving speed from two levels, regardless of the above two modes.

Since movement of the operator's point of view can be controlled, the usable virtual space is increased. In the past, when the operator moves in the virtual space, he (she) had to move actually to change his (her) position in the virtual space. Since the sensing range of the operator sensor was 2 – 3 m, the operator was not allowed out of that range. With the above new function, however, the operator can move freely in the virtual space by moving his (her) point of view without moving actually. The moving range of the operator in the virtual space is limitless. If necessary, the operator can move more than 100 m.

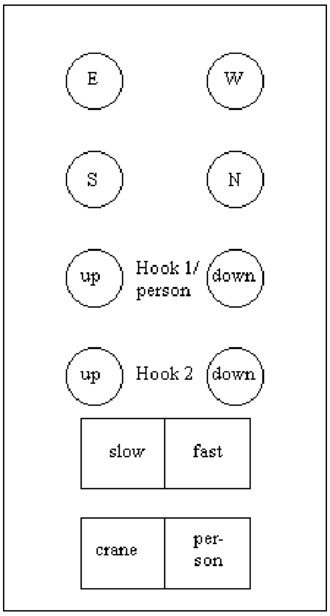

Fig. 9 Layout of operation panel

(4) Dynamic motion of suspended part and handling of it with virtual hand

It is usual that the operator of a crane in an assembly place pushes the suspended part with the hand to change its direction. This action also needs to be simulated. To simulate this action, the movement of the part must be simulated dynamically first, considering the mass of the part. In other words, the suspended part must swing around the fulcrum of the crane hook. Once the swing of the part is simulated, if an external force to push the part can be added, the motion of the part can be controlled. If the information on the fulcrum on the crane hook and the center of gravity, mass, and moment of inertia of the part is obtained, the swing of the part can be described. We obtained the information on the mass and moment of inertia from the CAD data first and obtained the information on the position of the part on the VADE in real time. Since we could not obtain the general solution of the swing of a part, unless the part had a very simple shape, we obtained the position and speed of the part by the numerical analysis method of 4th order Runge-Kutta. (**Fig. 10**)

After we succeeded in expressing the above motion, we generated an event of pushing the part when the virtual hand touches the part by utilizing the interference check function which is one of the basic functions of the BASE-VADE and converted the force to push the part at this time into a value and added it as an external force. Even if the operator extends his (her) hand, he (she) simply cuts the air. Accordingly, we calculated the pushing force by an expression considering from the speed, acceleration, pushing position, and moving direction of the virtual hand. Since a force larger than the force calculated by this expression is not applied, the condition was reproduced precisely. As a result, we succeeded in avoiding such an unpractical simulation that the operator was able to rotate a very heavy part easily. We also succeeded in avoiding a simulation that the operator pulled the part while his (her) hand was in contact with the part without applying any pulling force to the part. **Fig. 11** is the photo of the actual simulation work. The operator is pushing the part suspended by the crane in the virtual space with the virtual hand through the HMD (This state is shown on the display screen at the left far part of the photo).

After the above functions were added, we could carry press parts with cranes and assemble them. **Fig. 12** is a snapshot of simulation of carrying a press part with a carne. Since the realism of the virtual space is improved by using the photos of the actual assembly place (by means of texture mapping), the operator can execute the simulation in an environment which is similar to reality.

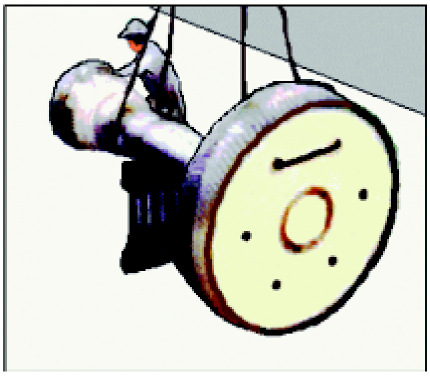

Fig. 10 Example of work (Transportation by crane)

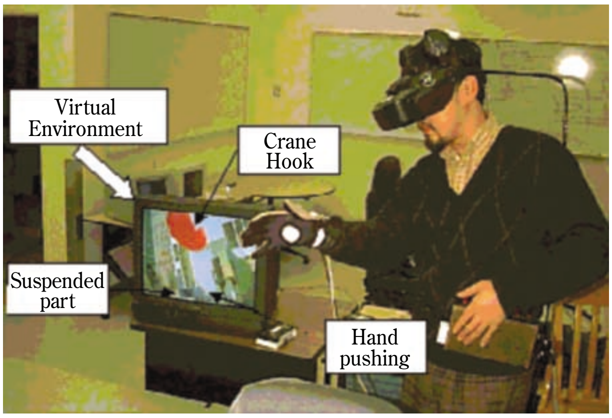

Fig. 11 Simulation by VADE

Operator pushes suspended part with virtual hand to change its direction.

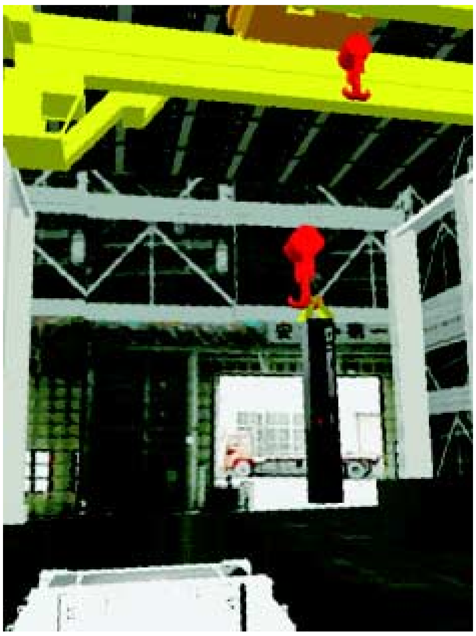

Fig. 12 Simulation of transportation by VADE

4. Effectiveness of virtual assembly

The purpose of the above virtual assembly is to shorten the total lead time and reduce the cost. To be concrete, the purpose is to find and prevent troubles which can occur in the field and make up a better assembly procedure by utilizing 3-dimensional models. The conventional examination of productivity is executed 2-dimensionally on paper. It takes a long time and sufficient information cannot obtained for the time consumed. As a result, productivity is judged by the experience and intuition of expert manufacturing engineers in many cases. Even if problems in the main check items are solved by taking a long time, those in the minor check items cannot be solved sufficiently or are not examined at all in the worst case for the lack of usable information.

With a virtual assembly tool such as VADE, anyone can examine productivity and find problems visually, easily, and precisely. If we simulate a portion which seems to have a problem, we can see and judge the result and can solve the problem by changing the shape of the model. Accordingly, we can improve the productivity efficiently and precisely.

5. Summary

After the functions of the BASE-VADE were improved, we could simulate assembly and disassembly work of large parts (of large-sized presses, in particular) with a crane. We can now change the design BOM to the manufacturing BOM and handle a part suspended by a crane with the virtual hand for simulation of the actual assembly work. Since the VADE has the minimum necessary functions, we should strive to improve it further through practical operations.

Introduction of the writer

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[A few words from the writer]

Virtual reality is an effective means for anyone to see portions which have been difficult to see and examine productivity. If assembly work is simulated in a virtual space and problems which seem to occur actually are detected and solved in the development stage, the total lead time should be shortened and the cost should be reduced. It is impossible, however, to put the all real phenomena in the virtual space. Accordingly, I should show my abilities, as an engineer, in construction of a system to grasp problems securely and find a means to solve them with less functions. I intend to continue improving activities for this purpose.