Development of an Expert System for Welding Design Support: an Attempt

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Abstract

Recently structures are becoming more and more large-scaled, complicated and diverse and their operating conditions are getting more and more severe. And the need for securing structural integrity is rapidly growing. Especially the weldments are one of the most important parts in terms of structural integrity assurance. But such being the situation, too much efforts are required on the part of welding engineers to secure good quality weldments. Thus, development of support systems for welding engineers is strongly called for to reduce the amount of their labors and to provide them with the working environments where they can make appropriate decisions with much ease and with less efforts.

Therefore, an attempt has been made in this work to develop a decision support software system for engineers in terms of welding design. As an initial phase of this work, an "expert system" for supporting engineers to make decisions against weld cracking was developed using Prolog and the effectiveness of the present approach was verified through TSS sessions.

KEY WORDS: (Welding Design Support, Expert System, Knowledge Engineering, Prolog)

1. Introduction

Recently structures are becoming more and more large-scaled, complicated and diverse and their operating conditions are getting more and more severe. And the need for securing structural integrity is rapidly growing. Therefore, the task of securing structural integrity calls for far greater efforts than before. Especially weldments are one of the most important parts in terms of structural integrity assurance. But since (1) the situations of structures are being as such and (2) the phenomena in welding are too much complicated with too many and too diverse factors and furthermore (3) the progress and extension of welding technology are quite remarkable, too much efforts are required on the part of welding engineers to secure good quality weldments. Thus, development of support systems for welding engineers is strongly called for to reduce the amount of their labors and to provide them with the working environments where they can make appropriate decisions with much ease and with less efforts.

Therefore, an attempt has been made in this work to develop a decision support software system for engineers in terms of welding design. As an initial phase of this work, an "expert system" for supporting engineers to make decisions against weld cracking was developed using Prolog and the effectiveness of the present approach was verified through TSS sessions.

2. Architecture of the system

Fig. 1 shows the architecture of the present system for a welding design. As the figure shows, the system is composed of five major subsystems; short term memory, rule base, inquiry subsystem, heuristic knowledge memory and control & inference engine.

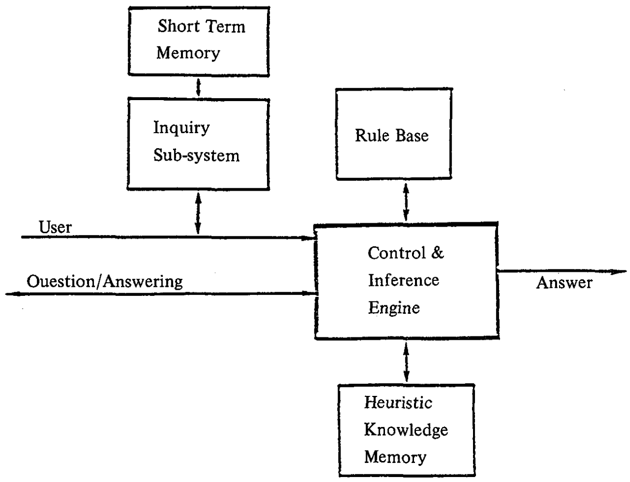

Fig. 1 Architecture of the present system for a welding design

Short term memory: This subsystem contains factual knowledge of specific cases obtained through computer-user conversation as data.

Rule base: This subsystem stores an assembly of pieces of

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engineering knowledge in the form of production rules. The computer infers by combining the pieces of knowledge in the rule base based on the inputted factual knowledge. The production rule is written in the form of IF . . . THEN . . . . If the factual knowledge of a specific case pattern-matches with the CONDITION part, the ACTION part is triggered on and the CONDITION part of another rule is invoked.

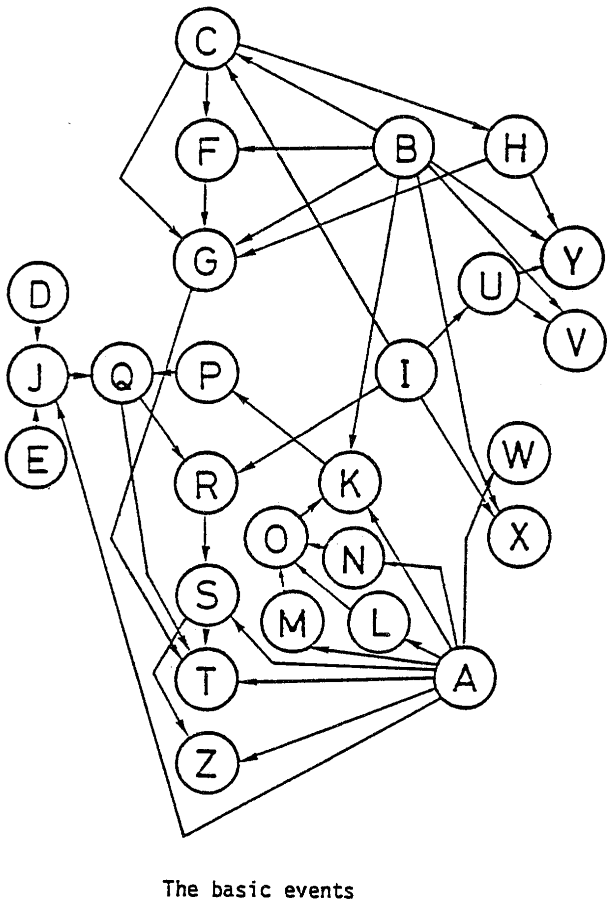
Heuristic knowledge memory: This subsystem contains pieces of knowledge experts obtained from experiences or logically ambiguous pieces of knowledge which cannot be systematized as those in the rule base. The programming language Prolog makes it quite easy to add, correct and delete these pieces of heuristic knowledge even while running the system.

Inquiry subsystem: This is an interface between computer and user. This functions as a dictionary of welding technical terms and manages the short term memory which stores factual knowledge of a specific case.

Control & inference engine: There are cases where more than one rules pattern-match with the inputted factural knowledge. If such is the case, the extension of search space increases exponentially. This subsystem functions so as to cut down unnecessary searching by selecting appropriate rules in the rule base through the application of knowledge obtained from experience.

3. Knowledge base

As too many factors affect weld cracking in a too much complicated manner, it is not easy to follow the logical sequences. Therefore, cause and effect relations in weld cracking are modelled using a directed graph to clarify the logical sequences for computer processing as shown in **Fig. 2**.



A= MATERIAL-TYPE
B= PALTE-THICKNESS
C= WELDING-METHOD
D= HUMIDITY-IN-WELDING-ENVIRONMENT
E= WELDING-MATERIAL
F= GROOVE-TYPE
G= LAYER
H= NUMBER-OF-LAYER
I= HEATING-INPUT
J= HYDROGEN-VALUE
K= PCM
L= CHEMICAL-COMPOSITION-C
M= CHEMICAL-COMPOSITION-MN
N= CHEMICAL-COMPOSITION-SI
O= CHEMICAL-COMPOSITION-SUM
P= P-CW
Q= PREHEATING-TEMPERATURE
R= COOLING-TIME
S= METAL-STRUCTURE
T= TOUGHNESS-IN-WELDED-JOINTS
U= EVALUATE-DEFORMATION
V= ANGULAR-DISTORTION
W= TENSILE-RESIDUAL-STRESS-WIDTH
X= MAXIMUM-RESIDUAL-STRESS-VALUE
Y= TRANSVERSE-SHRINKAGE
Z= HARDNESS-IN- WELDED-JOINTS

Fig. 2 Directed graph representation of the logical network for a welding design

In the rule base such quantitative relations as Pcm and chemical compositions or equations for an angular distortion and a tranverse shrinkage, and qualitative relations are contained.

But there are cases where information is incomplete and a factor cannot be evaluated if given information is used. For such cases, rules are stored in heuristic knowledge memory which can evaluate the factor using empirical knowledge. Pcm estimation or initial hydrogen content estimation are such examples. In the practical fabrication, however, welding conditions are often determined considering such an engineering common sense for example that a SAW is employed for better efficiency, although a SMAW is more preferable if quality alone is considered. Such "common sense" of welding engineers are also contained in heuristic knowldge memory.

4. An example of a TSS session

```
>>WELD
   THE QUESTION ABOUT MATERIAL-TYPE
1 : HT50
2 : HT60
3 : HT80
   ENTER 1 THRU 3 OF INTEGERS
IF YOU WANT TO KNOW ABOUT MATERIAL-TYPE,
INPUT (HELP)
—:1
                    •
                    •
== PCM == MUST BE 0.158 CRACK-SENSITIVITY.
IF YOU AGREE WITH THE SYSTEM'S DECISION,
TYPE "Y", OTHERWISE TYPE "N" (BACKTRACKING
TAKES PLACE).
—:Y
== WELDING-METHOD == MUST BE ONE OF (MA-
NUAL SUBMERGE). IF YOU LIKE TO MAKE SOME
RESTRICTION ON THIS ITEM, (INCLUDING ADOP-
TION OF THE SYSTEM'S PREFERRED VALUE) TYPE
"Y". IF YOU DO NOT LIKE TO MAKE ANY REST-
RICTION AND YOU LIKE TO LET THE SYSTEM GO
AHEAD, TYPE "N". IF YOU THINK NONE OF THE
SYSTEM'S PREPARED ALTERNATIVES APPROP-
RIATE FOR THIS ITEM, TYPE "B" (BACKTRACKING
TAKES PLACE).
—:Y
1 : MANUAL
2 : SUBMERGE
   ENTER 1 THRU 2 OF INTEGERS (MAY BE MUL-
   TIPLE) (U FOR UNKNOWN)
IF YOU WANT TO KNOW ABOUT WELDING-ME-
THOD, INPUT (HELP)
—:1
   THE QUESTION ABOUT HUMIDITY-IN-WELDING-
   ENVIRONMENT
1 : DRY
2 : WET
   ENTER 1 THRU 2 OF INTEGERS
IF YOU WANT TO KNOW ABOUT HUMIDITY-IN-
WELDING-ENVIRONMENT, INPUT (HELP)
—:1
==WELDING-MATERIAL == MUST BE ONE OF
(LOW-HYDROGEN-TYPE SUPER-LOW-HYDROGEN-
TYPE).
IF YOU LIKE TO MAKE SOME RESTRICTION ON
THIS ITEM, (INCLUDING ADOPTION OF THE
SYSTEM'S PREFERRED VALUE) TYPE "Y".
IF YOU DO NOT LIKE TO MAKE ANY RESTRICTION
AND YOU LIKE TO LET THE SYSTEM GO AHEAD,
TYPE "N".
IF YOU THINK NONE OF THE SYSTEM'S PREPARED
ALTERNATIVES APPROPRIATE FOR THIS ITEM,
TYPE "B" (BACKTRACKING TAKES PLACE).
                    •
                    •
                    •
                    •
                    •
1 : LOW-HYDROGEN-TYPE
2 : SUPER-LOW-HYDROGEN-TYPE
   ENTER 1 THRU 2 OF INTEGERS (MAY BE MULTI-
   PLE) (U FOR UNKNOWN)
IF YOU WANT TO KNOW ABOUT WELDING-MATE-
RIAL, INPUT (HELP)
—:1
==GROOVE-TYPE ==MUST BE ONE OF (H-SHAPE U-
SHAPE).
IF YOU LIKE TO MAKE SOME RESTRICTION ON
THIS ITEM, (INCLUDING ADOPTION OF THE SYS-
TEM'S PREFERRED VALUE) TYPE "Y".
IF YOU DO NOT LIKE TO MAKE ANY RESTRICTION
AND YOU LIKE TO LET THE SYSTEM GO AHEAD,
TYPE "N".
IF YOU THINK NONE OF THE SYSTEM'S PREPARED
ALTERNATIVES APPROPRIATE FOR THIS ITEM,
```

TYPE "B" (BACKTRACKING TAKES PLACE).
—:
Y

1 : H-SHAPE
2 : U-SHAPE

ENTER 1 THRU 2 OF INTEGERS (MAY BE MULTIPLE) (U FOR UNKNOWN)

IF YOU WANT TO KNOW ABOUT GROOVE-TYPE, INPUT (HELP)
—:2

•
•
•

== INPUT-HEATING == MUST BE BETWEEN 24.00 AND 42.00 (KJ//CM).
IF, YOU LIKE TO MAKE SOME RESTRICTION ON THIS ITEM, (INCLUDING ADOPTION OF THE SYSTEM'S PREFERRED VALUE) TYPE "Y".
IF YOU DO NOT LIKE TO MAKE ANY RESTRICTION AND YOU LIKE TO LET THE SYSTEM GO AHEAD, TYPE "N".
IF YOU THINK NONE OF THE SYSTEM'S PREPARED ALTERNATIVES APPROPRIATE FOR THIS ITEM, TYPE "B" (BACKTRACKING TAKES PLACE).
—:Y
ENTER A REAL NUMBER
BETWEEN 24.00 AND 42.00 (KJ//CM)
(MAY BE A TYPE OF "UNDER 1.0 "," "OVER 1.0" OR (U FOR UNKNOWN))

IF YOU WANT TO KNOW ABOUT INPUT-HEATING, INPUT (HELP)
—:24.0

•
•
•

== PREHEATING-TEMPERATURE == MUST BE BETWEEN 93.00 AND 149.00 (DEGREE).

IF YOU LIKE TO MAKE SOME RESTRICTION ON THIS ITEM. (INCLUDING ADOPTION OF THE SYSTEM'S PREFERRED VALUE) TYPE "Y".
IF YOU DO NOT LIKE TO MAKE ANY RESTRICTION AND YOU LIKE TO LET THE SYSTEM GO AHEAD, TYPE "N".
IF YOU THINK NONE OF THE SYSTEM'S PREPARED ALTERNATIVES APPROPRIATE FOR THIS ITEM, TYPE "B" (BACKTRACKING TAKES PLACE).
—:Y

ENTER A REAL NUMBER
BETWEEN 93.00 AND 149.00 (DEGREE)
(MAY BE A TYPE OF "UNDER 1.0", "OVER 1.0" OR (U FOR UNKNOWN))

IF YOU WANT TO KNOW ABOUT PREHEATING-TEMPERATURE, INPUT (HELP)
—:
93.0

== METAL-STRUCTURE == MUST BE UPPER-BAINITE.
IF YOU AGREE WITH THE SYSTEM'S DECISION, TYPE "Y", OTHERWISE TYPE "N" (BACKTRACKING TAKES PLACE).
—:Y

== TOUGHNESS-IN-WELDED-JOINTS == MUST BE TOUGH.
IF YOU AGREE WITH THE SYSTEM'S DECISION, TYPE "Y", OTHERWISE TYPE "N" (BACKTRACKING TAKES PLACE).
—:
Y

== ANGULAR-DISTORTION == MUST BE BETWEEN 17.41 AND 116.85 (RAD//1000)
IF YOU LIKE TO MAKE SOME RESTRICTION ON THIS ITEM, (INCLUDING ADOPTION OF THE SYSTEM'S PREFERRED VALUE) TYPE "Y".
IF YOU DO NOT LIKE TO MAKE ANY RESTRICTION AND YOU LIKE TO LET THE SYSTEM GO AHEAD, TYPE "N".
IF YOU THINK NONE OF THE SYSTEM'S PREPARED ALTERNATIVES APPROPRIATE FOR THIS ITEM, TYPE "B" (BACKTRACKING TAKES PLACE).
—:Y

ENTER A REAL NUMBER
BETWEEN 17.14 AND 116.85 (RAD//1000)
(MAY BE A TYPE OF "UNDER 1.0", "OVER 1.0" OR (U FOR UNKNOWN))

IF YOU WANT TO KNOW ABOUT ANGULAR-DISTORTION, INPUT (HELP)
—:18.0

== TENSILE-RESIDUAL-STRESS-WIDTH == MUST BE 4.80 (MM).
IF YOU AGREE WITH THE SYSTEM'S DECISION, TYPE "Y", OTHERWISE TYPE "N" (BACKTRACKING TAKES PLACE).
—:
Y

•
•

== TRANSVERSE-SHRINKAGE == MUST BE BETWEEN 0.00 AND 20.00 (MM).
IF YOU LIKE TO MAKE SOME RESTRICTION ON

THIS ITEM, (INCLUDING ADOPTION OF THE SYSTEM'S PREFERRED VALUE) TYPE "Y".
IF YOU DO NOT LIKE TO MAKE ANY RESTRICTION AND YOU LIKE TO LET THE SYSTEM GO AHEAD, TYPE "N".
IF YOU THINK NONE OF THE SYSTEM'S PREPARED ALTERNATIVES APPROPRIATE FOR THIS ITEM, TYPE "B" (BACKTRACKING TAKES PLACE).

—:Y

ENTER A REAL NUMBER
BETWEEN 0.00 AND 20.00 (MM)
(MAY BE A TYPE OF "UNDER 1.0", "OVER 1.0" OR (U FOR UNKNOWN))
IF YOU WANT TO KNOW ABOUT TRANSVERSE-SHRINKAGE, INPUT (HELP)
—:10.0

== HARDNESS-IN-WELDED-JOINTS == MUST BE "HV300-350".
IF YOU AGREE WITH THE SYSTEM'S DECISION, TYPE "Y", OTHERWISE TYPE "N" (BACKTRACKING TAKES PLACE).
—:Y

WE HAVE CLEADER ALL OF THE RULES

WELDING PROFILE

MATERIAL-TYPE	. . . HT50
CHEMICAL-COMPOSITION-C	. . . 0.100 (%)
CHEMICAL-COMPOSITION-MN	. . . 1.00 (%)
CHEMICAL-COMPOSITION-SI	. . . 0.240 (%)
PLATE-THICKNESS	. . . 30.00 (MM)
PCM	. . . 0.158 CRACK-SENSITIVITY
WELDING-METHOD	. . . MANUAL
HUMIDITY-IN-WELDING-ENVIRONMENT	. . . DRY
WELDING-MATERIAL	. . . LOW-HYDROGEN-TYPE
GROOVE-TYPE	. . . U-SHAPE
NUMBER-OF-LAYER	. . . 6
INPUT-HEATING	. . . 24.00 (KJ//CM)
HYDROGEN-VALUE	. . . (CC//100G)
P-CW	. . . 0.224 (CRACK-SENSITIVITY-FACTOR
PREHEATING-TEMPERATURE	. . . 93.00 (DEGREE)
COOLING-TIME	. . . 41.19 (SEC)
METAL-STRUCTURE	. . . UPPER-BAINITE
TOUGHNESS-IN-WELDED-JOINTS	. . . TOUGH
ANGULAR-DISTORTION	. . . 18.00 (RAD//1000)
TENSILE-RESIDUAL-STRESS-WIDTH	. . . 4.80 (MM)
TRANSVERSE-SHRINKAGE	. . . 10.00 (MM)
HARDNESS-IN-WELDED-JOINTS	. . . "HV300-350"

:(QUIT)

5. Summary

This work is an attempt to provide welding engineers with a decision support tool for design using an interactive computer system. As an initial phase of the study, an "expert system" to help engineers prevent weld cracking has been developed by using the programming language Prolog.

Although the prevention of weld cracking is vital in terms of securing structural integrity, the decision as to how to prevent it is not easy, since too many and too diverse factors are involved. Furthermore, in the practical fabrication, decisions have to be made under quite complicated conditions and not only systematized knowledge but also knowledge obtained from experience plays quite an important role in decision-making.

In this work, "knowledge engineering" approach has been introduced to develop the system. And for this purpose, knowledge on weld cracking is rearranged in the form of a directed graph to clarify the logical relations and to facilitate computer processing. In the directed graph, logical relations are expressed in the units of binary relations. Therefore, the programming language Prolog has been employed because it can represent binary relations more easily than Lisp or other languages.

As the developed system is still in its initial phase and the emphasis of the purpose of this study is more on verifying the effectiveness of the present approach rather than to develop an immediately usable system for practical applications, more amount of knowledge must be implemented and the quality of these pieces of knowledge must be examined to make this system really practical and usable. But the following points are made clear through the development of the system and TSS sessions with it.

(1) As the greater part of the program correspond directly to knowledge and programming grammar is quite simple, welding engineers can judge with ease whether the program is good or not appropriate.

(2) Welding engineers can implement their pieces of knowledge and converse with a computer according to their ways of logical reasoning which are based on their own respective engineering fields without being forced to follow the lines of reasoning predetermined by other engineers with the backgrounds different from theirs.
In other words, the present approach is expected to provide engineers of different backgrounds with the common tool to communicate so that more appropiate decision could be made with more ease by integrating different sources of information.

(3) The system can be run at any level correspondingly to the amount of knowledge implemented. This implies that the most up-to-date knowledge can be utilized

without being bothered by the old knowledge of the far past implementation time. To put it differently, new pieces of knowledge and experience can be implemented quite easily so that old experiences can be reexamined and reevaluated and that what are lacking for solving the problem can be readily detected through TSS sessions.

Finally, it may be safely concluded that the present approach is expected to provide a quite good man-machine interface for welding design engineers and to greatly reduce their rapidly growing amount of labor in decision making in design.

References

1) H. Nakashima: "Prolog/KR Users' Manual", Computer Centre, University of Tokyo (1982).