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A KNOWLEDGE-BASED DIAGNOSIS SYSTEM FOR WELDING MACHINE PROBLEM SOLVING

P. de BONNIERES, J.L. BOUTES, M.A. CALAS, S. PARA

NOTES ET DOCUMENTS

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A knowledge-based diagnosis system for welding machine problem-solving

P. de Bonnières	Knowledge Engineer	FRAMENTEC
J.L. Boutes	Welding Engineer	FRAMATOME
M.A. Calas	Knowledge Engineer	FRAMENTEC
S. Para	Knowledge Engineer	FRAMENTEC

SUMMARY

This paper presents a knowledge-based diagnosis system which can be a valuable aid in resolving malfunctions and failures encountered using the automatic hot-wire TIG weld cladding process.

This knowledge-based system is currently under evaluation by welding operators at the Framatome heavy fabricating facility. Extension to other welding processes is being considered.

A DIAGNOSIS SYSTEM FOR WELDING PROBLEM-SOLVING

Purpose of system

Prior to employing a new welding process in fabrication, it must be thoroughly checked out by development engineers to ensure process reliability and compliance with quality acceptance criteria.

Transferring the process to the production line entails transmitting comprehensive knowledge of the process as well. Traditionally, this has been handled by training or through the use of formal documents (procedures, welding work sheets, etc...).

Now, however, knowledge-based diagnosis systems can provide a solution to the problem of knowledge transfer by incorporating all the expertise relevant to a given process in a single information package, accessible to all users of the process. In addition, diagnosis systems permit on-going modification of the knowledge base so that it can be adapted to changing know-how or new applications.

Malfunctions during welding

Two main causes of malfunction are encountered during automatic welding operations:

1. *Wear or failure of various system components,*

2. *Non-compliance with welding procedure, especially incorrect setting of equipment parameters.*

Malfunction, in turn, can lead to two types of problem:

1. *Weld machine malfunctions,*

2. *Weld defects such as insufficient weld bead thickness.*

The welding diagnosis system presented in this paper provides a means both for diagnosing the causes of a malfunction and solving the problems resulting from it.

Diagnosis system characteristics

From the outset, the welding diagnosis system was engineered around a portable micro-computer. It was designed with end users in mind. End users were consulted extensively during the design process.

Special attention was paid to human factors when developing this system. The following matters features were incorporated to facilitate use:

- a computer keyboard interlocking system to prevent operator typing errors,
- computer screen windowing to facilitate use of different system functions (data call-up, system status update, causal reasoning, test point location list, supplementary function menu).

Apart from the main diagnosis objective, supplementary functions (such as display of repair procedures) were developed to aid in correction of malfunctions and to provide friendly communications, e.g. user aids, summary reply display, malfunction location aids, functional explanations).

Initial application: hot wire TIG cladding

A new weld cladding process, known as the hot wire Tungsten Inert Gas (TIG) or Gas Tungsten Arc Welding (GTAW) process, was installed at the Framatome Chalon sur Saône heavy fabricating works in 1985. Developed at the Framatome Welding Research and Development Center, this process replaces the manual Shielded Metal Arc Welding (SMAW) process formerly used to clad nozzle seal lips.

Because of the complex technology employed and the wealth of experience already acquired by the Welding Research Center in this area, assuring a representative knowledge base, this process was selected for the first application of the welding diagnosis system.

DESIGN BASES

Expert systems for diagnosis

The first expert systems designed for diagnosis included a knowledge base made of statements linking symptoms to the malfunction affecting the process to be diagnosed. In such systems, symptoms are considered merely as evidence of system malfunction, and they are investigated without any causal considerations. This type of diagnostic approach is embodied in so-called surface evidential systems (1).

As opposed, other works aim at basing the diagnosis on causal reasoning. This approach consists of reproducing the overall behaviour of the device under diagnosis through a description of its knowledge structure and *creation of a functional model of its basic descriptive entities. The difference between empirical observation and the modelled entities provide clues to the causes of the malfunction.*

The two different approaches have often been the subject of comparative studies (see, for example, (5) and (7)). From an industrial standpoint, the evidential system approach has the following drawbacks:

- *as no causal connections are provided, the validity of knowledge remains strictly limited to the domain for which it was designed. Therefore, such pieces of knowledge cannot be reused, even in closely related domains (5).*

- *acquisition of this type of knowledge is strictly dependent on individual know-how and the quality of the communication skills of the expert. Furthermore, no external comparative criteria are available to validate the knowledge during the acquisition phase. The expert provides the only warranty of its effectiveness.*

- *finally, since the diagnosis rules do not embody causal reasoning, the explanations which this type of system provides have no real interest for the end user.*

Although the causal approach may be able to resolve some of the problems outlined above, it has yet to be proved suitable for practical diagnosis of complex systems.

The approach adopted must therefore avoid the drawbacks of surface evidential systems while being efficient enough to handle diagnosis of complex machines.

Approach used

Design principles

To eliminate the obstacles presented by surface systems, it is not necessary to model the behaviour of each component part of the device (4). Incident diagnosis - the type of diagnosis problem-solving under consideration here -does not require forecasts of the equipment state. In any case, industrial machines are usually equipped with lamps, announciators and indicators providing data on the state of some components. Thus, the data that must be fed into the model is that which can be obtained through empirical observation of machine behaviour.

This does not mean that all attempts at explicit causal reasoning has been abandoned. Note that the basic rules for describing a chunk of knowledge in a surface system are divided into distinct semantic levels. In diagnosing technical problems, each observable property (as shown on lamps and indicators, etc.) is a symptom of equipment malfunction. By combining these symptoms, the cause of the malfunction can be established.

The principle used in finding a solution to the problem is to link all the individual observations taken to the functional structure of the machine. It is no longer necessary to combine the various premises into one specific rule because this combination relies on generalised laws concerned with *functional description of the machine. In other words, unlike surface systems, no hard-and-fast rules are established beforehand; rules are simply constituted as the reasoning process progresses.*

Therefore, a prerequisite for this diagnosis approach is a description of the welding machine being diagnosed (descriptive knowledge) and a way of actually processing description data when determining the cause of malfunction (strategic knowledge).

Descriptive knowledge

This type of how-to knowledge is provided by the welding machine description. This is an expression of the knowledge involved in operation of the equipment as a whole and of its component parts. It describes the equipment function, the significance of observable properties, possible malfunctions and the possible causes of such malfunctions.

Descriptive knowledge has an objective foundation. This is true not only of observable properties such as lamp status, but also of various operating stages of the device, which correspond to distinct physical states of the device or of one of its parts. However, the relationship between the symptoms encountered and the malfunctioning descriptive entities is established just like the results of expertise, without causal justification. In this respect the welding diagnosis system is similar to a surface system.

It should be noted that all such knowledge can simply be expressed in the form of statements.

Strategic knowledge

The type of knowledge represented by diagnosis rules embodies how the descriptive knowledge is used to diagnose malfunctions. This knowledge governs the order in which the various components in the machine are tested; it is independent of descriptive data.

STAGES OF OPERATION

Operating stages

Weld machine operation can be divided into successive stages of operation, each of different duration. During each of these stages, the state of the machine can be considered as stable. They are defined as being operating stages produced by specific actions of the operator or controller. An active subset of operations and components corresponds to each of these phases.

It should be emphasised that some of these actions are so brief that the operator may be totally unaware of the stages into which they are broken down. The knowledge system must therefore differentiate between these functional operationing stages and a quite different sequence of operations which the user might identify himself, enabling the malfunction to be positively situated with respect to welding operation.

Installation description

The description of the device chosen for diagnosis is organized into four hierarchical levels: circuits, elements, families of components and components.

The first three levels are functionally defined. A functional object can embody several physical objects. Conversely, the same physical object may belong to several functional objects when it participates in more than one equipment function.

The fourth level (components) is strictly physical: it embodies all machine parts which may fail such as fuses, connections, relays and electronic components, etc. It also embraces parameters such as current, voltage and velocity which may cause component malfunction if improperly set.

Functional objects classed in the same hierarchical level are not necessarily independent; they may, in fact, be quite interdependent. To provide a valid description, such interdependency must be taken into account. This problem is broached in paragraph "Relationship between modelled entities".

Circuits

A welding machine may be considered as being an assembly of circuits designed to provide the various "fluids" required for welding operations to be performed. The term "fluids", as used here, means all that contributes to performance of the weld. It includes, for instance, electrical power source, coolant, shielding gas, arc power supply, and filler metal heating power. The mechanical systems producing the relative motion of mechanical parts (i.e. oscillation and servocontrol) are also assimilated to circuits, where the "fluid" is the physical work produced. In the same manner, the filler metal wire itself is also considered a fluid.

Each circuit is given a unique description characterised by the fluids it provides. A single circuit may perform several functions if, for example, it distributes fluids to several systems. Finally, each function can be characterised by its behaviour, such as whether a fluid is present or not, and by its characteristic parameters (flow rate, pressure, current, velocity, etc.).

Elements

Each circuit is divided into elements which contribute to its function. Three main types of elements can be distinguished, namely a generator for generating the fluid required, a check/control component used to either check or regulate fluid parameters, and a transport element, which is a means to bring the fluid to the location where it is consumed.

Component families

Each element is made up of component families linked together by the functions they perform. These families are mutually exclusive and depend on the circuit to which they belong.

Components

This lowermost hierarchical level contains physical component parts and the operating setting (which are responsible for the malfunctions observed by the operator).

DIAGNOSIS OF WELDING MALFUNCTION

Reasoning procedure

Welding malfunctions, and the stage in the welding operation at which these malfunctions occur, are the two initial pieces of data fed into the system..

By assigning malfunctions to a precise stage in the welding job, it is possible to formulate one or more plausible hypotheses to explain the cause of the malfunction. Such hypotheses express abnormal behaviour of one function of a given circuit, e.g. :

"control console power outage"

or

"off-normal arc generator coolant pressure".

Validation of these hypotheses depends on analysis of observable properties (status lamp on or off, parameter values, status of power supply, etc.). This makes it possible to establish or reject a suspected triple (circuit, function, behaviour).

Then the elements of the technical system contributing to the abnormal function are identified. Here too, observable properties can be checked to isolate the abnormal element and then similarly, the family of components in which the defective part is situated. The last step involves pinpointing the defective component.

System reasoning is thus carried down to the component level. It relies on the additional information requested by the knowledge system as the investigation proceeds.

Strategy

The search for the cause of a malfunction through the various levels of description is carried out on the basis of the strategic knowledge, which describes the strategy of the diagnosis system. Strategy depends on the relationship between modelled entities, the adequacy of indications and the sequence of observable properties of the device.

Relationship between modelled entities

In order to be able to draw satisfactory logical conclusions from information provided by observation, the diagnosis system must know the relationship that exists between various entities of each level of descriptive knowledge.

For instance, arc strike failure may be due, among other causes, to :

- control console power source failure
- absence of shield gas at the torch tip,
- high frequency arc strike power supply failure.

Nevertheless, the first hypothesis explains the other two perfectly well. Therefore, there exists a relation, which we may call an "antecedence" relationship, between the power source and the presence or absence of shield gas, on the one hand, and the power source and provision of suitable high-frequency power, on the other.

The existence of this "antecedence" concept determines chains of entities, and the interpretation of indications related to the various modelled entities takes into consideration the fact that these entities belong to distinct chains.

It follows that where an indication is normal, the corresponding element, together with all upstream objects in the same are normal also, and need no longer be considered in the investigation (even if they belong to other chains of entities as well). However, where an indication is abnormal, all elementary objects in chains of entities to which the corresponding object does not belong are considered normal.

Adequacy of indications

The welding machine does not have the testing ressources to check out all functional entities comprising the description. It is thus not always possible to confirm all the hypotheses issued at all levels of description. In such a case, it is unreasonable to closely examine hypotheses which cannot be validated, and just as unreasonable to fully reject these hypotheses out of hand.

The solution is (1) to begin by a surface diagnosis of the hypothesis in question ; (2) to move on to other assumptions of the same level if this diagnosis is fruitless ; and (3) to investigate the original hypothesis in greater depth at some later time if necessary. Several hypotheses can be examined "in parallel" until one of them is confirmed.

Sequence of observations

Problem-solving must be effected in a given sequence, which depends on the application to which the device is put during diagnosis. For example, certain types of malfunction may endanger operators or threaten the device itself. In this case, the search begin by diagnosing the most urgent observations.

General procedure, however, is to carry out a few straightforward observations first (e.g. read lamp status), followed by more and more complicated tests as the investigation proceeds. The system performs the search in accordance with criteria selected by the expert, taking into account the level of description attributed to each category of observable properties. This level also determines the limits of the search when testing non-confirmable hypotheses (see above).

The diagnosis system is implemented using the M.1 knowledge-based system development tool.

Using the knowledge representation language provided by M1, the descriptive knowledge has been written into predicate calculus formulae while the strategic knowledge has been embodied into production rules which manipulate these formulae.

To improve the efficiency of the diagnosis system and reduce diagnosis ressource requirements, the knowledge base is split between several data files.

This arrangement is made possible by the functional breakdown of the machine description. Thus it is only necessary to store on main memory the minimum amount of knowledge necessary to handle system reasoning.

<u>Size of knowledge base</u>

In the application addressed in this paper, the knowledge base contains all knowledge currently available to the welding and welding machine (TIG hot wire) domain expert. In particular, it incorporates not only the various past malfunctions occurring during machine engineering and development, but also all potential causes foreseen by the expert on the basis of this knowledge of machine design and the welding process.

The functional description comprises 612 entities arranged on four levels of description and linked by 155 antecedence relationships. Analysis of 160 observation points makes it possible to pinpoint one of the 200 possible causes of malfunction. The complexity of the diagnosis process lies in the multiplicity of paths leading to each possible malfunction.

<u>PERFORMANCE AND FUTURE PROSPECTS</u>

In our opinion, the approach developed here offers a number of advantages over other diagnosis systems :

Developing the functional description of the machine supplies a sound framework for the acquisition of knowledge. It allows "knowledge engineer" to "get a firm handle on the expert" and to guarantee the consistency of knowledge fed into the system. One of the principal benefits is increased development efficiency: this system, for example, was developed in just six months.

Only descriptive knowledge is liable to change if the application or design is modified. This separation between description and strategy makes it possible to alter the descriptive knowledge. In the application presented in this paper, continual updating of the knowledge base is seen as a logical extension of the plant maintenance activity. Moreover, knowledge update can be performed by personnel having only a cursory knowledge of programming techniques.

Explanations for malfunction given by the diagnosis system are generated at the descriptive level. They manipulate the entities in the description and not the system rules. This gives them real meaning for the user.

If conclusive diagnosis is not possible because of lack of knowledge, intermediate conclusions arrived at using the system at least allow the origin of the malfunction to be located in terms of descriptive data. Degradation of system expertise in such cases is thus gradual, and allows the case to be referred to an expert for a more refined description of the relevant entity.

Further possibilities offered by the system are presently being reviewed :

The system's underlying knowledge principle could be used to create a useful knowledge information acquisition tool.

System architecture makes it possible to acquire information directly from sensors mounted on the welding machine.

Diagnoses could be provided to users together with a statistical exploitation of the cause of the malfunction. Such statistical data would be of use not only for maintenance purposes, but for improving system efficiency as well. They would oblige the system to start a diagnosis search by testing for the most frequently-encountered causes of malfunctions, the list of which would be updated internally after each diagnosis.

This evaluation aims to answer the following questions:

Can this type of system truly be used by ordinary welding operators, or does it require the acquisition of special skills?

Does the knowledge structure used allow pertinent diagnosis irrespective of the complexity of the malfunction?

Can new knowledge be readily acquired, both from the standpoint of data acquisition and knowledge base modification?

In addition to these technical considerations, two other important question marks remain:

What amount of cost savings can such systems generate, and how can these savings be evaluated?

To what degree will use of such systems require existing production facilities to be modified?

Only a real industrial experiment may answer such questions.

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