PCSEX: An expert system for pump contamination sensitivity evaluation

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ABSTRACT
The Pump Contamination Sensitive Expert System (PCSEX) introduced in this paper is a new package being developed as a complementing technique to present wear test procedures for determining the contaminant tolerance of hydraulic control system pumps. Present wear-test examination of a pump’s contaminant tolerance requires special testing facilities and follows a complicated and tedious procedure which is expensive and time consuming work. PCSEX is based on knowledge integration of a large amount of data from previous testing, and expertise acquired from previous experience. It also integrates the defined model or formula associated with a user’s particular system structure, and some equations available in research reports. PCSEX has been developed using GURU, an expert system development environment which supports a broad range of integrated knowledge processing capabilities, and allows the production of intelligent application systems.

KEYWORDS

INTRODUCTION
Much research has been devoted to testing and analysis of the contamination sensitivity of hydraulic control system pumps. Procedures for determining a pump’s contaminant tolerance (Omega Rating Method) are available. An Omega Rating, is based on the normalized residual performance as defined by the flow degradation ratio versus the corresponding test dust size range applied to the pump. The contamination sensitive signature is a plot of degradation ratio versus the corresponding upper size range.

The main core of PCSEX is a knowledge base which possesses the ability to accurately interpret complex patterns and other data in the context of equipment types and operating circumstances. The knowledge of PCSEX is based on the fact that there are specific or certain relationships between Omega Rating and Pump Service Life; Leakage rating; Particle Size of Contaminant; Pump Type; Operating Conditions of System. These relationships and informations become the knowledge base of PCSEX.

PCSEX integrates large amounts of data from previous testing and expertise acquired from previous experience. It also integrates models or formulae which are associated with a user’s system structure. One of the important capabilities of PCSEX is the ability to deal effectively with imprecise, incomplete and uncertain information. The goal variable values (Omega Rating) obtained from different knowledge sources may be different. Each of the knowledge sources draws its uncertainty from both uncertainty of input variables and from incomplete knowledge or errors. Employing fuzzy algorithms and certainty-factor algebra, PCSEX calculates all fuzzy values and their respective certainty factors, then weights all fuzzy values according to its own uncertainty factor to obtain more accurate goal values.

KNOWLEDGE SOURCES OF PCSEX AND THEIR UNCERTAINTIES
PCSEX is being developed as an efficient, convenient tool to determine a pump’s Omega Rating. The knowledge base configuration of PCSEX is
Fig. 1 Knowledge Base Configuration of PCSEX

shown on Fig 1. Ability to handle uncertain data by inference and a reasoning process is crucial to the success of machine intelligence programs. PCSEX emulates capabilities of a human expert’s ability to deal effectively with imprecise, incomplete and uncertain information. Proper use of the knowledge sources and fuzzy algorithms and certain-factor algebra helps achievement of more accurate goal values, with confidence.

In PCSEX, the relationship between Omega Rating and related information is represented by knowledge which is stored in three kinds of knowledge patterns. They are [1]:

1. Possibilistic Knowledge Pattern
2. Probabilistic Knowledge Pattern
3. Deterministic knowledge Pattern

which all include some incompletions, and have some degree of uncertainty. Each of the knowledge sources includes its uncertainty from uncertainty of input variables, from incomplete knowledge, or from errors. The goal variable (Omega Rating) obtained from different knowledge sources may have different values. All of the evidence is used together with the conclusions associated with them.

Users of PCSEX are required to enter the uncertainty factors with their data and information during consulting PCSEX. PCSEX handles uncertain data by an inbuilt inference reasoning process.

The knowledge PCSEX uses, and approaches to deal with the uncertainties of the knowledge, will be introduced.

POSSIBILISTIC KNOWLEDGE OF PCSEX

The possibilistic knowledge is used to predetermine pump Omega Rating. PCSEX uses an IF-premise and THEN-action clause to set up matching through which a predetermined value of Omega Rating is obtained, as illustrated on Fig. 2.
Possibilistic knowledge focuses primarily on imprecision and introduces some uncertainty, which is intrinsic in expert knowledge presented in natural language.

**PROBABALISTIC KNOWLEDGE OF PCSEX**

The objective is to refine Omega Rating according to Pump Leakage Rate and to Particles Size Range. Probabilistic knowledge is used to adjust and improve the Omega Rating. Essentially, a pump’s Omega Rating is determined by conducting a contaminant sensitivity test. Such a test gives the amount of degradation with respect to size range of a contaminant exposed at the rated operating conditions. In most cases, the degradation is normalized with initial conditions to provide a performance degradation ratio relative to each contaminant size-range. To adjust the value of Omega Rating obtained from possibilistic knowledge, quantitative descriptions of relationships between pump omega value, current pump leakage, and particles size range of contaminant is required and is fixed in the rules of PCSEX. Such a specification is based on a reasonably large number of repetitive tests (3000 raw data from 172 pump tests) [2]. Fig. 3 shows degradation of different particle size for tested pumps [2]. From the database, the probabilistic leakage rating can be accessed by input corresponding to the predetermined omega value and particle size range of system. That is:

\[ q_{db} = f(\omega, P_{size}) \]

where: \( q_{db} \) is leakage rate data extracted from database
\( \omega \) is predetermined omega rating
\( P_{size} \) is particles size range

The comparison of \( q_r \) (actual leakage of system) and \( q_{db} \) (leakage rate from database) is expressed as Eqn. 2,

\[ \delta q = q_{db} - q_r \]

\( \delta q \) can be employed to adjust omega \( (\omega_0) \). A \( \delta q \) larger than 0, implies that the \( \omega_0 \) may be smaller than it should be; \( \delta q \) smaller than 0 implies that \( \omega_0 \) may be larger than it should be. An adjusted omega value, \( \omega_1 \), is derived in terms of \( \delta q \) as shown in Eqn. 3.

\[ \omega_1 = \omega_0 \left( 1 + \frac{\delta q}{q_r} \right) \]

**DETERMINISTIC KNOWLEDGE OF PCSEX**

Omega value is greatly affected by system operating conditions. The omega \( \omega_0 \) should be amended to correspond to these operating conditions. Deterministic knowledge is based on a defined model or formulae which is associated with a system’s structure, and physical laws which describe system operation. The usefulness of such knowledge depends on the ability to make it machine and condition specific.

The Omega Rating depends on the 1000 hour contamination tolerance profile and the Beta ten filter curves. Graphically, when the profile is superimposed on the family of beta ten filter curves, the beta ten curve that is tangent to the profile is the rating of the pump. That is, the value of the Omega Rating is the Beta ten value of the filter which protects the pump for 1000 hours under certain conditions of structure, pressure, contamination level, and flow-rate. Thus, the nature of the Omega Rating sets up certainty relationships among a pump’s pressure, contamination ingress ratio, and pump service life.

**FUZZY VARIABLE CONTROL**

A fuzzy variable has a set of values varying in number from 0. In PCSEX, different knowledge sources and types lead to different values of Omega Rating with
different certainty factors. The Omega Rating is a fuzzy variable, which may be expressed as the following fuzzy set:

\[ \omega = \{ \omega_1: cf_{x_1}, \ldots, \omega_5: cf_{x_5} \} \] (4)

where \( \omega_i (i = 1 \ldots 5) \) is one of the \( \omega \) values and \( cf_{x_i} \) is the certainty factor of \( \omega_i \).

Equation 4 recognises that there are five useable knowledge sources relevant to the present work; \( \omega_0 \), \( \omega_1 \), and three from deterministic knowledge.

PCSEX lists all of the fuzzy values and its own certainty factor and calculates the Weighted Average Value of Omega Rating, which weights fuzzy value according to its own uncertain value. This is implemented in the DO section of PCSEX’s rule set.

IMPLEMENTATION OF PCSEX

PCSEX is a comprehensive program designed to interpret knowledge; it is being developed using the GURU shell [3]. GURU is an expert system development environment which supports a broad range of integrated knowledge processing capabilities. These include expert system creation and consultation, data management, ad hoc inquiry, screen management, spreadsheet analysis, statistics generation, programming, graphics, general-purpose text processing, elaborate report generation, and remote communications.

AN EXAMPLE OF CONSULTING PCSEX

Part of the frames which the operator would see during a typical consultation session are reproduced below in Fig. 4(a) through (f). They are largely self-explanatory, but the choice which will be selected in each frame is shown as a highlighted clause. The set of choices leads to 5 Omega Rating values with respective certainty factors and the goal value is obtained by weighing the 5 fuzzy values according to each’s own certainty factor. The report screens are shown in Fig. 4(e) and 4(f).

The result from this example shows the weighted average value of Omega Rating to be 3.207, which is from possibilistic knowledge. The Omega Rating value with the highest certainty factor is 3.227 and such a value is from probabilistic knowledge, which rectified predetermined omgea by pump actual leakage.

PCSEX also includes << Statistics Analysis for Comparison >> to help user to check or conform or compare the results obtained from consulting PCSEX with statistics data; << Introduction >> and << Help >> to help users to understand PCSEX and to know how to use PCSEX to obtain some knowledge relative to pump contamination tolerance to help make decisions. Fig. 5(a), (b), and (c) show three screens of Statistics Analysis.
4(c) Enter the Certainty Factor of Pump Service Life (Choice 3:60)

4(d) Enter System Current Contamination Level (choice 4: ISO 21/18)

4(e) Display Result by Spreadsheet

4(f) Final Report Screen

** FIG. 4 SOME PCSEX SCREENS **

(a) Using Statistic Analysis for Comparison

(b) Statistic Data from 172 Pump Omega Value Test
9. CONCLUSION

PCSEX, presented in this paper, is a computer package designed to assist in determining pump contaminant tolerance. PCSEX possesses the ability to interpret complex patterns and other data in the context of equipment types and operating circumstances. The goal variable in PCSEX is obtained from three different knowledge sources. Each of the knowledge sources draws its uncertainty from both uncertainty of input variables and from incomplete knowledge or errors. PCSEX employs fuzzy algorithms and certain-factor algebra to obtain more accurate goal values. PCSEX is being developed using GURU which is an expert system development environment which supports a broad range of integrated knowledge processing capabilities and allows the production of intelligent application systems. The current status of PCSEX is that its main body is complete, but we are still working on making it user friendly for others.

REFERENCES

