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FUZZY CONTROL OF INTERNAL COMBUSTION ENGINES

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ABSTRACT

To control a diesel engine in the process of testing, the principles of fuzzy output, which are widely used in fuzzy-logic controller development, could be applied. Controller's main task is to monitor an external object, in which case the behavior of the monitored object is described by the fuzzy rules. The most important application area of fuzzy sets theory is the fuzzy logic controllers. Their operation slightly differs from the operation of common controllers. In order to describe the system, the expert knowledge is used instead of differential equations. Control of the automation systems for engine testing (ATS), using fuzzy-logic controller, should be based on a knowledge database with fuzzy rules. Such database could be created with expert knowledge, neural network, or direct measuring method. Development of an adaptive control system for diesel engine testing process based on fuzzy logic allows to simplify system's structural components and to provide discrete control procedure with some uninterruptible properties, which could improve the control and reduce the scope of the knowledge database. Fuzzy logic makes it fairly simple to input a priory information about an object in the form of fuzzy control rules into the adaptive control system. Similarity of form and natural language relatively easy allows to obtain necessary expert knowledge. A prior information provides one of the key initial conditions of the system developed according to adaptive control method – the condition of supreme initial adaptation.

KEY WORDS
control; network; diagnostic; system; engine.

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INTRODUCTION

The knowledge database is a crucial component of diesel engine testing intelligence system. The knowledge database is a set of facts and inference rules, supposing logical inference and intelligent data processing [1].

This database consists of three levels.

The first level includes linguistic variables. These variables are put together by the process engineers at the stage of test development with regard to a specific engine model. The variables should include the parameters necessary to setup and control the testing procedures. Linguistic variables are filled in by the experts in this particular area and with the help of direct measuring methods. Basic limits and the number of linguistic variables, together with the type of membership function, should be defined at this level. The number of linguistic variables depends on the control accuracy. However, this will require more time to fill in the knowledge database. This level also contains syntactic and semantic rules for the linguistic variables.

The second level contains fuzzy rules used to convert the given parameters into the control ones. These rules are composed from the linguistic variables defined at the previous level. They can be set by the experts, with the help of direct measuring methods, or by the self-learning neural network. In the latter case, the level will be completed with data fully automatically. This level also includes semantic rules, which define the feasibility of testing. For example, it is impossible to obtain maximum power or torque under given minimum speed. These rules also allow to avoid fault situations.

The third level contains the priority vectors used to range engine characteristics. The priority vectors consist of set parameters. They can be used to focus the tests, i.e. to test ecological properties, power, or economic efficiency of the engine.

The ATS for diesel engines provides a feedback during testing procedures. This feedback allows both to fix the results and adjust the control inputs, and to complete the knowledge database with the help of case study method.

MATERIALS AND METHODS

Case-based inference is a method of decision-making that uses the knowledge about previously occurred situations or accidents (cases). When considering a new problem (current situation), a similar case should be found to be used as a precedent. It is possible to use a solution developed for a similar case, adjusting it to the new conditions of the current case, if necessary, instead of searching a solution for a new case each time from the very beginning. After the current case has been processed, it can be introduced into the case database together with its solution for possible further application [2].

A case includes:

- problem description;
- problem solution;
- result (validity) of solution application.

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Problem description should contain all information necessary to achieve the goal of the inference (the selection of the most relevant solution). In the ATS for diesel engines, problem description represents the types of engine operating conditions.

Result description can contain information about positioning of controls at a certain point, execution results, restoring method (in case of failure), description of operations to be performed in order to avoid the failure, restoring results. Result description can also include the references to other cases, or additional text information.

A case may contain not only the positive results. It is necessary to save information about the failures of application of some specific operating conditions in order to avoid their further usage. Descriptions of failures and their causes can be used in future. The system can store explanations of a decision and even its alternatives [3].

Case study method includes the following stages:

- extraction of the most relevant cases for the current situation from the case database;
- adjustment of the selected solution to the current situation, if necessary;
- solution application;
- application evaluation (validity check);
- adding and saving of current case into the case database.

Let's consider database completion under dynamic conditions of diesel engine testing as an example [4]. In this case a fuzzy rule will be as follows:

IF ωi AND Rj THEN hi

Where

ωi – is the crankshaft (engine) speed (ω1, ω2, ω3,..., ωn);
Rj – is the engine operating condition (R-R; ...R-1; R0 ; R1...; Rr);
hi – is the rack displacement (h1, h2, ... hn).

These rules can be used to create the database for steady-state engine operating conditions. In this case the level Rj will have a fixed value of R0. This means that the engine is working under a condition, when the speed is neither increasing, nor decreasing [5]. The database of the steady-state conditions will be defined as follows:

IF ωi AND R0 THEN hk

where

ωi – is the engine speed (ω1, ω2, ω3,..., ωn),
R0 – is the steady-state engine operating condition,
hk – is the rack displacement (h1, h2, ... hl).

The level Rj is completed with the help of case study method. Let's assume that we have the control rule:

IF ωk AND R1 THEN hx

where

ωk, R1 – are the fixed linguistic variables of the variables ωi and Rj,

hx – is the unknown value of the variable hk.

Let's find the nearest case to complete this rule. The nearest rule is the following:

IF ωk AND R0 THEN hs

where

ωk, R0, hs – are fixed linguistic variables of variables ωi, Rj and hk.

Let's create two new fuzzy rules based on this case:

IF ωk AND R1 THEN hs
IF ωk AND R1 THEN hs+1

Control value of the rule 1 coincides with the nearest case, while for the rule 2 the nearest linguistic variable located towards mutable variable Rj should be taken (if the variable Rj of a new rule is higher, than that of the case, then the control value shifts upwards towards the value of the nearest linguistic variable, otherwise – downwards).

The result of the first rule application is known, as it fully coincides with the case. The result of the second rule should be checked under the self-learning mode. If the result of the first rule is more accurate, then it should be used as a basis and the database completion comes to an end. Otherwise, the rule 2 becomes the rule 1, while the rule 2 should be developed again on the basis of the next linguistic variable:

IF ωk AND R1 THEN hs+1
IF ωk AND R1 THEN hs+2

Both rules should be tested for accuracy, and, if the rule 1 more accurate, then it should also be taken as a basis. Otherwise, the replacement, similar to that mentioned above, should be performed.

If the most accurate rule doesn't meet the required accuracy, then an intermediate linguistic variable should be introduced, using intersection operation [6]. If the assignment of the basic value to two nearest variables is equally possible, then a new linguistic variable should be created there.

Introduction of a new linguistic variable will make it possible to develop the following control rule:

IF ωk AND R1 THEN hs+1, s+2

If this rule meets the required accuracy, then it is retained in the database [7]. Otherwise, a new linguistic variable should be created within the limits of two linguistic variables with the smallest measure of inaccuracy.

The number of linguistic variables is limited by the digit capacity of the fuzzy controller. Increased number of linguistic variables can affect real-time operation mode.

Application of this method will allow to reduce time required for knowledge database creation and to improve the accuracy of control, while increasing the number of tests [8]. Case study method application also allows to adjust the knowledge database created for one engine to another engine with slightly different characteristics. Time required to create the database will depend on how the operation conditions differ.

RESULTS AND DISCUSSION

The process of development of the ATS for diesel engines on the basis of control flow chart with fuzzy controller application represents the following sequence of stages [9].

The upper level represents the testing procedure, namely the document, regulating the performance of all types of diesel engine tests.

It contains the key aspects of the tests: purpose and goal, scope, condition for selection of a test object, testing equipment, testing conditions and testing procedure, result estimation methods, technical and fire safety requirements, industrial health requirements [10]. Testing procedure is developed by the process engineer, who takes into account all necessary engine parameters [11]. While developing the procedure, the process engineer should specify engine characteristics, which he would like to obtain as the output result [12]. The ATS for diesel engines will automatically select optimal control parameters to execute specified modes.

At the next stage the above-mentioned testing procedure is represented in the form of patterns [13]. A pattern is a sequence of changing modes, each of which could be represented as a segment, which X-component corresponds to mode run-time, while Y-component characterizes the changes in a measured parameter for that time period.

While the graphical representation is more convenient to a human being, a machine uses numeric data for processing [14]. Therefore, the conversion of the patterns into a summary table of parameters should be performed at the next stage [15, 16, 17, 18, 19]. For this purpose, test time should be divided into the time intervals tmin, at which engine operation control will be executed. A time interval should be as small as possible to provide improved control accuracy and to avoid fault situations. However, reduced time intervals require significant computing facilities. The number of points, at which the control will be executed during the testing procedure, is defined by ratio:

$$S = t_{is} / t_{min}$$

where

S – is the number of points;

tis – is total test time;

tmin – a time interval between two control points.

Further, the values of measured parameters (A1i, A2i, A3i,..., Ami) should be assigned to each time interval, where Ai is the parameter values at a certain point derived from respective patterns. This data is saved in the summary table of parameters.

It is worthwhile to apply fuzzy logic to the objects characterized by a large number of uncertainties, for example, in case of inaccurate information received from the actuators, or inaccuracy of the model of the monitored objects and engine control [21, 22, 23, 24]. The results of control will be considered appropriate, if they fall within the corresponding limits [25]. Fuzzy logic application with regard to diesel engine testing procedure control allows to assess aggregate impact of each parameter on the final computation result, while the ignorance of the minor parameters by the other methods leads to erroneous outcome.

CONCLUSIONS

The above methods are characterized by one essential fault, lying in the fact that all parameters included into the fuzzy rules equally influence on the output characteristic. As a result, it is impossible to develop the focused tests. For example, when performing the fuel consumption test, fuel consumption parameter will be of primary importance. This parameter should be also considered in wearing test, though it will be less significant. To avoid this shortcoming, it is necessary to develop a system, controlling the impact of each specific parameter on the final result.

CONFLICT OF INTEREST

There is no conflict of interest.

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