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CALIBRATION OF MICROPROCESSOR CONTROL SYSTEMS FOR SPECIFIED LEVELS OF ENGINE EXHAUST TOXICITY

Abstract

A fast experimental procedure for the calibration of internal combustion engines microprocessor control systems is proposed. This procedure is based on using a new approach to the solution of many-parametric optimization problems with constraints. The main benefit of this approach is that it requires a minimum number of experimental measurements where the measurements can have a high level of noise stability to the inaccuracy of measurements and adjustments. The efficiency of the suggested procedure is demonstrated by the search for air-fuel ratio, ignition timing and exhaust recirculation optimum bounded control that provide for the minimum fuel consumption for each speed-load regime at a given emission level. The optimization problem was defined by three variables and three constraints.

Key Words: automatic control, evolutionary optimization, engine exhaust toxicity, engine fuel efficiency

Introduction

Achieving high efficiency of automotive engines at a specified level of exhaust gases' emissions poses a problem of many conflicting demands. Satisfying such demands could be achieved by using a microprocessor control system (MS). The optimum control of the elements regulating the engine is mainly realized through an appropriate selection of all control contours calibration. The toxicity and efficiency of an engine are evaluated according to their integral indexes for the sum of regimes of the working cycle. Therefore, calibration of the MS requires the solution of complex multi-parametric and multi-objective problems of optimization.

When using the experimental data for the calibration of MS, it is necessary to use fast optimization methods that allow us to make a decision based on a small number of experiments. It is known that the efficiency of the classic methods of non-linear programming (MNP) depends on topology of the objective function and constraints. The experience accumulated during the solution of a number of real MS calibrating problems confirmed that the topology of the objective and the constraint functions are not only complex, but could be different according to their classifications - even, uni-modal, multi-extremal, raven, etc. In case of the absence of *a priori* information about the objective function and constraints topology, it is difficult to choose the proper method of the non-linear programming. Our experience in some practical optimization and control problems allows us to state that the highest effectiveness can be achieved with a help of structured parametric optimization methods that are practically invariant to the topology of the functions to be optimized and that allow for the automatic adaptation of the search parameters during the process of the extremum searching.

The Indirect Optimization method based on Self-Organization (IOSO) is the algorithm that was developed by the lead author and has been used for the solution of these types of problems. IOSO is a novel evolutionary optimization algorithm for the robust solution of complex practical problems characterized by the following features.

1 Ability to deal with complex and not *a prori* known topology of the objective function space and constraints.
2 Ability to find a global minimum with a minimum number of numerical or experimental evaluations of the objective functions.
3 Ability to deal efficiently with the large dimensionality of the problem to be solved (up to 100 variables and more);
4 Ability to deal with non-differentiable objective functions.

A Real-Life Example

As a real-life demonstration of its capabilities, the efficiency of the suggested optimum control method was experimentally checked on a 16-valve engine with V = 1500 cm^3. The engine was equipped with the MS which included the electronic system of the fuel supply with the feedback on the λ-probe, ignition timing control system, turbulent flow intensity control system (tampers in the inlet collector are dosing the quantity of the gang air through one of the two inlet dampers for each cylinder) and the system of the exhaust recirculation optimum control.

As an illustrative example we chose the regime from the driving cycle area that has the essential timing "weight" in the matrix of the equivalent regimes corresponding to $n=2500\ min^{-1}$ and torque $M_e = 40\ Nm$. For the evaluation of the search algorithm the number of the controlled parameters was limited to three variables: ignition timing, exhaust recirculation and the intensity of turbulence in the flow. Such a set of independent variables corresponds to the concept of engine with a 3- components neutralizer ($\alpha = 1.0$) and a system of the exhaust recirculation optimum control for the purpose of increasing fuel economy and decreasing toxic characteristics of the engine. In order to exclude the possibility the detonation combustion, each time when the detonation occurs the objective function was penalized with the "jump" -like penalty.

Two experiments using IOSO were performed. The allowable ranges of the permissible values were limited as follows. Turbulent flow intensity was limited by the location of the turbulence flow dampers control from 0^o to 60^o (maximum turbulence flow). Exhaust recirculation (ER) was allowed to vary from 0% to 25% and the ignition timing (IT) from 10^o to 60^o. The optimization program chose the initial 10 points by utilizing a random number generator.

Figure 4 shows the optimization history of the optimum control search in the laboratory. Following values of accuracy "σ" of the preset and measured parameters were realized: *n* – 0.1%; *Me* –0.5%; turbulence flow – 1.5%; ER – 3.0%; IT – 1.5% *Ge* –0.4%; CO – 2.0%; CH – 2.0%; NO_x – 2.0%. The archived data demonstrate that even when rather high levels of random errors exist during the process of calibration, IOSO algorithm can be used with success for the fast experimental calibration of the automotive engine microprocessor control system with only 25-30 calls to the object function evaluation.

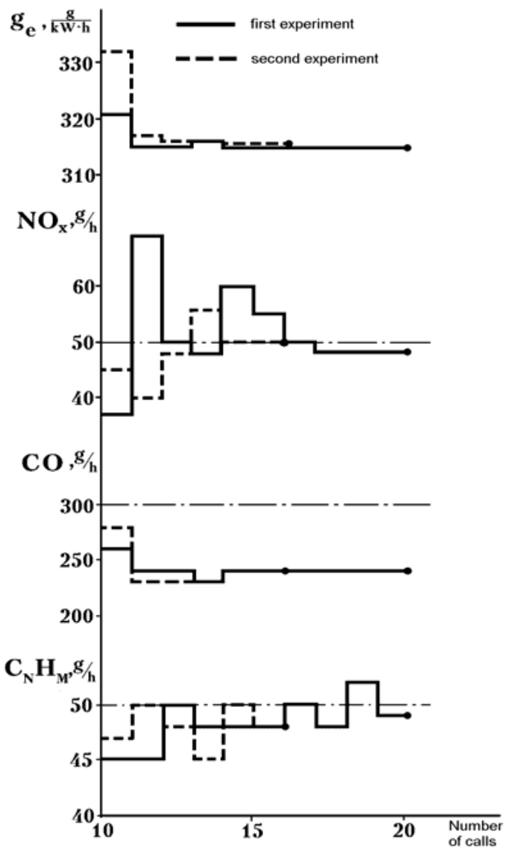

Fig. 4. Dynamic of experimental search

(constraints : NO_x-50 g/h , CO-300 g/h , C_NH_M-50 g/h).

Figure 5 and Figure 6 show the dynamic process of optimization of a real-life car engines VAZ-2112 and UMZ (two experiments). Note that for optimization of the modern UMZ engine there were two stages of minimization:

1. For acceleration when Δα of throttling is being constrained, and
2. For throttling when Δα of acceleration is being constrained.

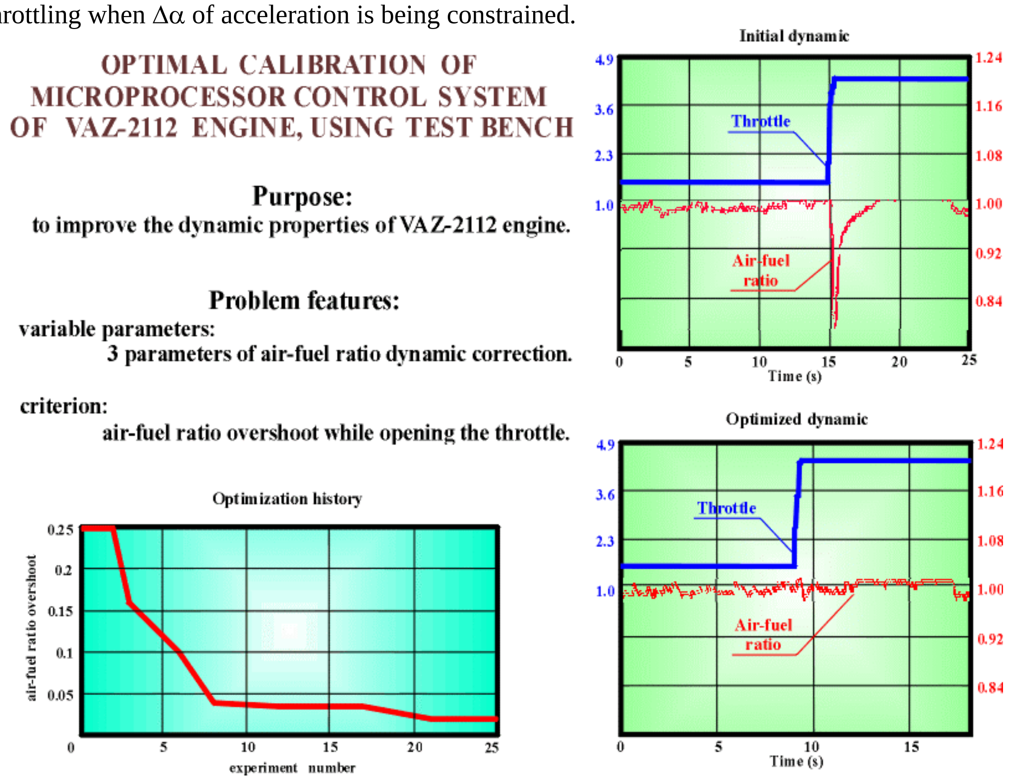

Figure 5. Optimal calibration of a multiprocessor control system of VAZ-2112 car engine to insure minimum undershoot of air-fuel ratio while opening the throttle.

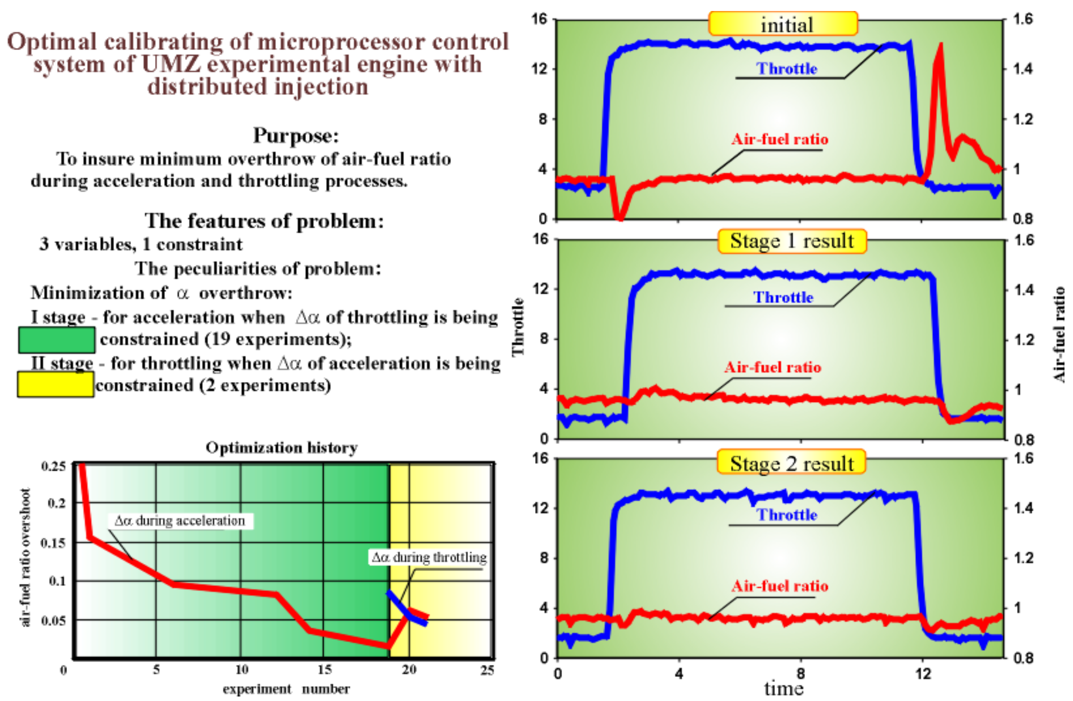

Figure 6. Optimal calibration of a multiprocessor control system of UMZ experimental car engine to insure minimum over/undershoot of air-fuel ratio during acceleration and throttling.

For solution of the second optimization problem (with both acceleration and throttling) we used a database that we obtained when we solved the first optimization problem. In this case, we needed only two new steps of experimental research. This shows that this procedure can use an existing database. In this case we can minimize the number of experimental data that are needed for solution of the optimization problems. Note that both experimental stands (in AutoVAZ and UMZ Company) allow up to 5.0 percent error of experimental measurements. This means that we are solving the optimization problem in a stochastic formulation and that this problem represents a robust design optimization. Figure 7 shows the experimental stand that we used for the solution of this practical optimization problem in the automotive industry.

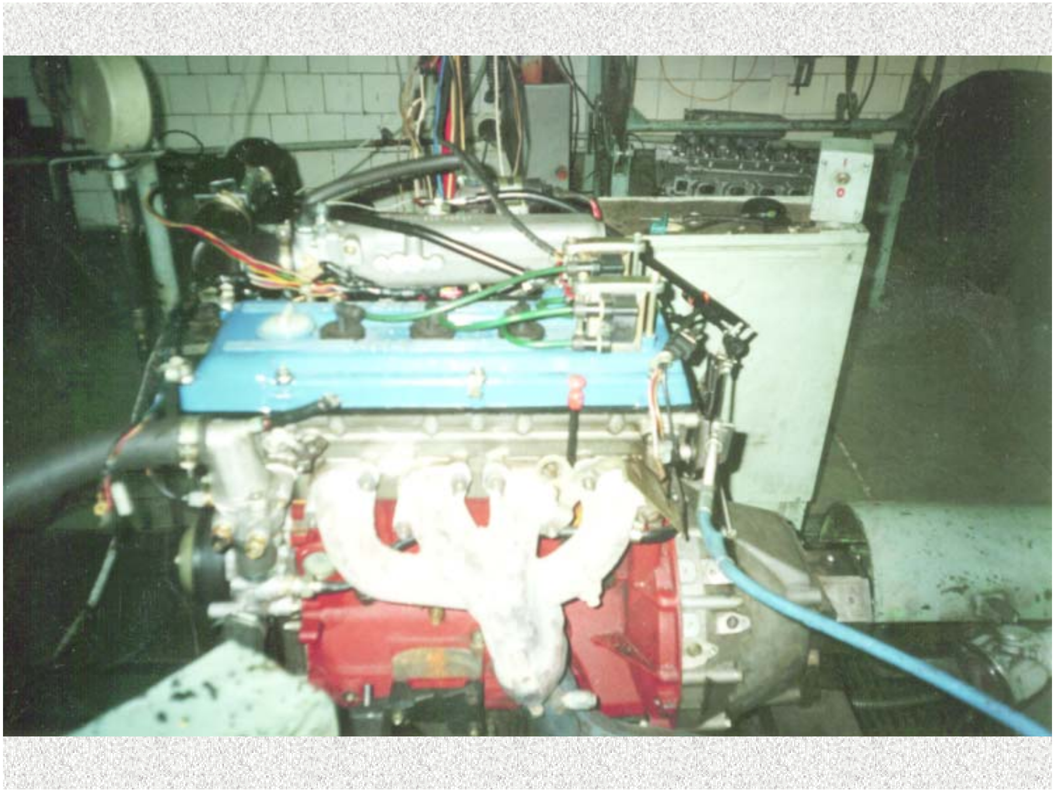

Figure 7. Experimental test stand for the AvtoVAZ car engine

Conclusions

A new robust optimization algorithm (IOSO) was shown to be highly efficient and reliable tool for calibration of microprocessor control systems in internal combustion engines when toxicity levels of the constituents in the exhaust gases are specified. IOSO was demonstrated to require significantly smaller number of experimental measurements when compared to other well-known optimization algorithms used for the same purpose. A multi-level optimization approach employing low-fidelity algorithms and a high-fidelity experimental evaluation of the objective functions of complex system like car engines has been demonstrated to work remarkably efficiently in case of real car engines during transient operating regimes.