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INTERNAL COMBUSTION ENGINE TEST PLAN EXECUTION ORDER OPTIMIZATION USING TRAVELLING SALESMAN PROBLEM HEURISTICS APPROACH

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For a given internal combustion (IC) engine stationary test plan, significant time savings during its realization could be achieved if the sequence of test points execution is adequately determined. The criterion for stabilizing the engine operating point is determined by the magnitude of the change in the most inert parameter, and in the general case, it is the temperature of the engine exhaust gases. A certain level of prior knowledge about the examined object is necessary to conduct such an analysis. If there are no results from previous tests, simulation models or experiences, the Slow Dynamic Slope (SDS) tests are a great way to quickly gather the necessary information. The idea of the SDS test is based on a slow continuous change of the control parameter. The continuous change of control parameter over time results in deviation (offset) of the measured output of the system in relation to the stationary values that will occur if the test was carried out as a quasi-stationary. The values and position of the offsets will depend on the system's characteristics (system gain, time constants) and the slope of the input. In the ideal case, when increasing the value of the control parameter during a test, we expect this offset to have some constant value, and when decreasing this parameter by the same intensity in the opposite direction, we expect the offset to be symmetrical. By determining the mean value of the response during the ascending and descending control slopes, an approximation is obtained that adequately corresponds to the results of the quasi-stationary test.
The task of finding the optimal sequence for a stationary engine testing plan can be set as Travelling Salesman Problem (TSP). This paper will present the application of one of the heuristic methods for solving the TSP on the example of testing the IC engine, which is a very complex dynamic system. Following this model, it is possible to optimize the stationary test plan for any other dynamic system.
Assuming that a sufficiently good test plan exists, further time savings in its execution can be achieved if a favourable sequence of execution of the operating points is determined. As it was emphasised, the criterion of stabilisation of the operating point is determined by the magnitude of the change of the most inert parameter, and in the general case, it is the temperature of the engine exhaust gases. The basic idea is to find such a sequence of stationary operating modes, during the implementation of which a minor deviation of the engine exhaust gas temperature is obtained. This will result in the shortest stabilisation time for a given series of operating points.

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For an examination plan of p = 45 points, an approximate $N \cong 6 \cdot 10^{55}$ potential combinations of execution order. Solving TSP by exhaustive numerical search belongs to the category of algorithms of factorial dependence of execution duration as a function of the number of parameters. Due to many such combinations, it is impossible to realise (execute) a program that will find the optimal solution through an exhaustive search on an ordinary computer.

Genetic algorithms enable a high level of flexibility in defining the way of changing the path vector, i.e., the previously mentioned mutations. Within the used genetic algorithm [17], mutations of the selected path vector are based on two of the randomly selected indices (points in the path) on which GA: Performs full rotation of path vector elements between specified indices (points); Replaces the value of the path vector at the given indices; Performs a phase shift of part of the path vector with an adequate displacement of one element. In this way, for every parent path, three modified paths are formed, for which the criterion function is determined and the process of further selection is carried out. All mentioned random choices are characterised by a uniform distribution of the probability function.

In the worst case, if the sequence of execution were randomly selected, the average deviation of the exhaust gas temperature would be about 140 °C. If the optimised execution order is determined based on the minimum distance criteria in the Engine Speed - Engine Torque operation space, the mean temperature deviation of exhaust gas temperature would be 34 °C. In the ideal case, for the known stationary test results, the mean value of the exhaust gas temperature deviation is 7.7 °C per operating point. If the models obtained from SDS testing were used to determine the optimal sequence, the mean values of the deviations per operating point would range from 20.5 °C to 9.2 °C, depending on the type and duration of the SDS experiment, which is very close to the ideal case.