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EVALUATION OF THE POSSIBILITY OF OCCURRENCE OF SELECTED DAMAGE TO A CAR ENGINE TURBOCHARGER USING THE EVENT TREE ANALYSIS (ETA)

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Abstract

The subject of the article is the identification of factors behind the incorrect operation of a car turbocharger that, in longer perspective, lead to the damage of the device. Due to the operating principle and design features, the device works with many engine systems – intake, exhaust, lubrication systems and also, increasingly more often, with the cooling system. A multitude of relations, complexity, and working conditions are reasons due to which the device is sensitive to disturbances of quality parameters of the working media (e.g. oil). In the article based on the selected causes of damage of turbochargers, we focused on the following initiating event, concerning the bearings lubrication system, which is clogged oil strainer. The authors aims at performing an analysis allowing to increase the detectability of emerging malfunctions that lead to deterioration of operating conditions of the device. For this task tool such as ETA (Event Tree Analysis) was used. It is a tool for assessing system and process safety. It facilitates detecting potential risks, as well as relations existing between actions or events. This method explores the path from the initiating event to the outcome (most often representing the immobilization of the tested object), with particular emphasis on intermediate stages affecting the technical condition of the object. Unlike the FTA analyses, which have a deductive nature, the ETA analysis is inductive. The analysis of the obtained results, supported with validation by means of ETA, allowed proving that, given the current state of knowledge and advancements in technology, it is possible to apply additional sensors for monitoring the operation of a turbocharger. The proposed modifications were considered minor design changes that significantly increase the reliability of the device.

Keywords: *turbocharger, combustion engines, Event Tree Analysis, ETA*

1. Introduction

Supercharging systems are widely applied in modern combustion engines. The most commonplace systems are turbochargers. They belong to a group of compressor chargers. The fundamental component of the system is the turbo-compressor – a flow machine, in which the rotors of the turbine and the compressor are fixed to a common shaft. Wide application of supercharging systems in modern engines results in an increased focus on the optimization of these systems in motor vehicles.

Turbochargers are relatively simple devices whose design has not changed in any significant way in recent years. However, this subassembly is still characterized by low durability that is heavily dependent on the adherence to the manufacturer operating recommendations. This is confirmed by the investigations described in [1]. From the performed analyses, it results that, despite technological advancement, the rate of malfunctions in piston engines has not improved. Engines are fitted with many technically advanced subassemblies, which reduce the engine durability and expose it to external factors. In the article, the authors have confirmed that the engine malfunction rate in relation to the charging systems has significantly deteriorated.

Due to the operating principle and design features, the turbocharger works with many engine systems – intake, exhaust, lubrication systems and also, increasingly more often, with the cooling system. A multitude of relations, complexity, and working conditions are reasons due to which the device is sensitive to disturbances of quality parameters of the working media. Working conditions of turbochargers are highly variable. Such devices, arranged in exhaust systems of combustion engines, are exposed to the following factors (among others): high temperatures, fluctuations of exhaust gases, vibrations caused by the operating engine and the movement of the vehicle, thermal shock caused by fluctuating temperature, impact loads.

As we see damage to turbochargers in modern combustion engines are a prevalent phenomenon and their sources should be sought in dysfunctions of the following systems: engine lubrication, intake, or exhaust systems (exhaust aftertreatment system).

Given the large scale of the phenomenon, the aim of the study was specified to determine the probabilities of occurrence of unwanted event, in case of disorders of quality parameters of the working media of the motor and turbocharger system. Based on the performed bench tests, the impact of safety systems on the work of the component was studied, and subsequently solutions that are more effective were proposed. In the article, the authors focused on a frequently occurring clogging of the engine oil strainer. The occurrence of such event would result in a complete immobilization of the component. An Event Tree was created for such case. To accomplish the task, safety barriers were used. The purpose of the barriers was to reduce negative effects of occurrences of initiating events. The calculation of probability of occurrences of various effects in each of the cases helped quantify the selected damage to the turbocharger.

2. Research methodology

In order to perform the investigations, a special test bench was designed for the testing of turbochargers (Fig. 1). A combustion engine was used for the tests – in this case, the engine was an exhaust generator. The main advantage of the bench is that the test conditions are as close as possible to the real conditions of a turbocharger coupled with an engine. Temperature, pressure, and pressure fluctuations are similar to those existing in the exhaust manifold of a supercharged combustion engine. For checking and recording parameters of factors in various branches of the system, temperature sensors and pressure converters were used.

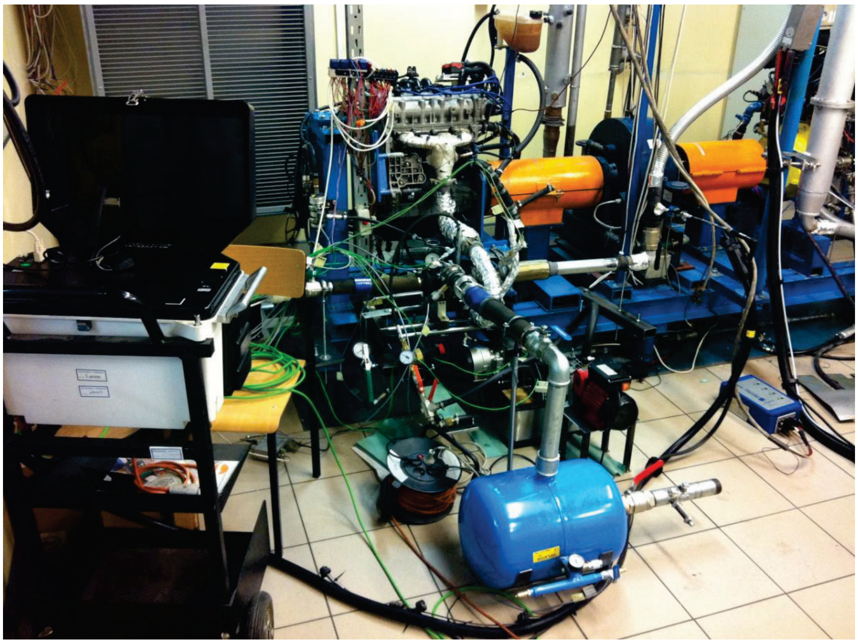

Fig. 1. Test bench with a combustion engine as a gas generator

The engine is equipped with a complete set of instruments for continuous operation, as well as power and torque regulation, making it possible to produce a controlled stream of exhaust gases at given parameters [2].

To evaluate the possibility of occurrence of the selected damage, the Event Tree Analysis was used. The ETA method is a technique for identifying and assessing a sequence of events resulting from an initiating event. The purpose of this analysis is to determine the distribution of potential severity of the risk connected with the initiating event, as well as identifying the impact of the effectiveness of instruments responding to the risk. There are two forms of ETA: pre-occurrence and post-occurrence. The pre-occurrence ETA makes it possible to test the effectiveness of neutralizing the severity of a risk. The post-occurrence ETA is used to analyse the materialized risk and opportunities of managing the level of its severity [3].

For the Event Tree method to be applied, it should be assumed that a major malfunction is a result of not just a single occurrence of an initiating event, but also the confluence of several events or a series of events [4]. The appearance of a single dysfunction does not generate a chain reaction, nor a serious malfunction. It is not until a sequence of adverse conditions appears, causing subsequent damages, that may result in serious malfunctions.

Using the ETA method, one can graphically present a sequence of events and barriers, beginning with initiating a state likely to cause anomalies and resulting in effects arising at each stage of the analysis. Most often, the barriers include safety systems (e.g. an air filter, a CO_2 sensor, or a fuse), as well as the human factor, which can directly minimize the effects of an occurrence of a malfunction (e.g. a CNC operator or a production line quality inspector). In this method, it is assumed that each event in a sequence is a success or a failure (no intermediate states).

The probabilities assigned to individual branches in Event Trees are conditional probabilities. When conducting the analysis at each stage, one needs to ask the question “what if?” The operating algorithm is based on analysing possibilities of evolving of the initiating event.

It is important to accurately determine safety barriers, which effectively limit negative effects of the initial event. The ETA method is a logical, divalent tree with the initiating event at the base and a root leading to the event with the most serious effect. Each barrier creates a branch which is also a result of the considered logic state: a success (yes) or a failure (no) depending on whether the given barrier is effective or not. Events arranged in the branches are combinations of sequences of consecutive events.

The result of the tree analysis is the systematization of all possible sequences of events concerning the adopted classification of effects (in case of studying a turbocharger it is the degree of damages, their extent and consequences possibly caused by the faulty component).

The ETA technique also makes it possible to calculate the probabilities of occurrence of each group of sequences.

In order to perform the analysis, it is necessary to estimate the probabilities of occurrence of the initiating events and the probabilities of occurrence of events at specific barriers, obtained from the bench tests. For the case discussed in this article, this step was performed based on the analysis of data concerning the most common faults occurring in turbochargers, which were provided to facilities specialized in regenerating components. The additionally applied estimates take into account community interviews with people leading the above facilities.

The ETA analysis was performed with the following steps:

1) Identifying initiating events, which could lead to a complete immobilization of the turbocharger – the so-called state of unfitness (in extreme cases of the entire engine).
2) Suggesting alternative solutions for securing the system from critical effects.
3) Creating an Event Tree.
4) Estimating the probabilities of occurrence of the initiating events and the occurrence of events at specific barriers.

5) Describing the malfunctions and determining their effects.
6) Calculating the probabilities of occurrence of a given type of effects for the existing and the proposed solutions.
7) Determining existing systems preventing the occurrence of an event or effects leading to the state of unfitness (so called safety barriers).

3. Results

The analysed initiating event, briefly referred to as the "clogged oil strainer" is marked on the tree as event A. This phenomenon may be caused by the deterioration of oil quality parameters (e.g. the occurrence of excess of tarry substances, coal etc.). Obstructed flow may also be caused by the accumulation of ice crystals on the strainer during a cold winter, when operating at low loads and short distances. Improper repair, residues of flushed sealants, gasket fragments or other foreign bodies can lead to a reduction in the passability of the oil strainer, which results in an obstructed oil flow. Event Tree with a graphically presented diagram is shown in Fig. 2.

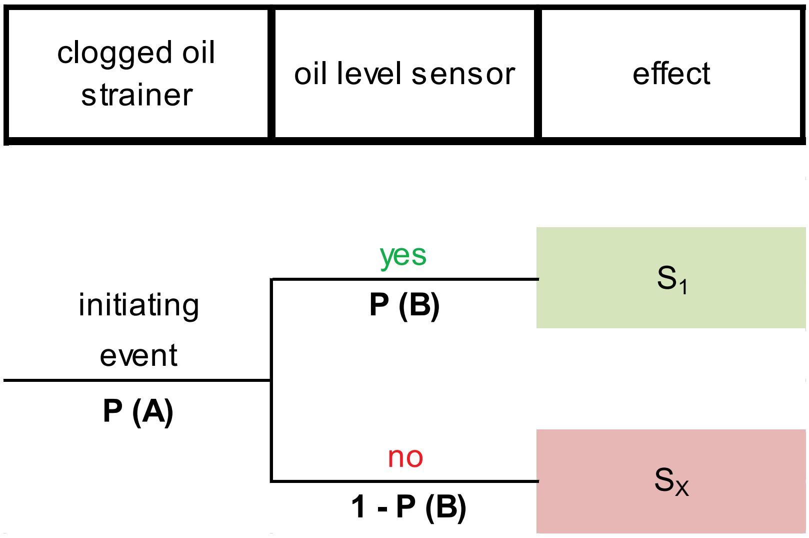

Fig. 2. Event Tree for the initiating event "clogged oil strainer"

In this case, the engine lubrication system contains only one safety barrier B – the oil pressure sensor. The main task of the sensor is to check the oil pressure in the combustion engine. However, this function does not provide proper control of the turbocharger lubrication components. In this case, the location of the lubrication system in the turbocharger is important. The most common solution, though disadvantageous from the point of view of reliability, is to locate the component at the end of the system, which enables the oil to reach the turbocharger at the latest. Consequently, precise information on the quantity and pressure of the fluid in bearings is missing. This significantly determines the reliability of the component.

The effects of different S events have the following interpretation:

– S1 – The sensor informs about drops in oil pressure. In practice, it means that the damage may have been caused by various issues, and consequences of the damage may affect many parts. The oil pressure sensor may also indicate a critically low oil level. Occurrence of a temporary interruption in oil supply can have serious consequences for a turbocharger. The intervention should include unclogging the oil strainer, flushing the engine oil sump, checking the oil pump, changing oil or refilling it and checking the play on the turbocharger shaft.
– SX – This effect is the critical value of occurrence of the lack of lubrication of shaft bearings. The intervention involves the removal of the cause of oil lack, flushing the oil sump, changing oil and replacing the filter with a new one, repairing or regenerating of the turbocharger.

Also in this case, the quantitative analysis of the success branch (to avoid the critical event) was described as P(S1, 2, 3 or 4) and the failure branch 1 – P(S1, 2, 3 or 4). The probability of occurrence of a given type of effects in quantitative terms is as follows:

$$P(S_1) = P(A) \cdot P(B), \tag{1}$$

$$P(S_X) = P(A) \cdot [1 - P(B)]. \tag{2}$$

The value of probability of occurrence of the initiating event was determined based on expertise and research as $P(A) = 0.1$. The probability of occurrence of event at barrier B equals: $P(B) = 0.1$. Numerical values of the probability of occurrence of a given type of an effect in quantitative terms equals:

$$P(S_1) = 0.01. \tag{3}$$

The probability of occurrence of a critical event is equal to:

$$P(S_X) = 0.9. \tag{4}$$

After calculating probabilities P(S1, 2, 3 or 4) and P(SX) for each discussed case, we proposed and introduced technical solutions for monitoring the selected operational parameters of the turbocharger. Taking into account the proposed improvements, we created analogical Event Trees and calculated the probability of occurrence of individual cases.

4. Solution

The analysed initiating event, referred to as the "clogged oil strainer", marked on the tree (Fig. 3) as event A. The proposed barriers in forms of a temperature sensor and a flow meter are indicated as C and D.

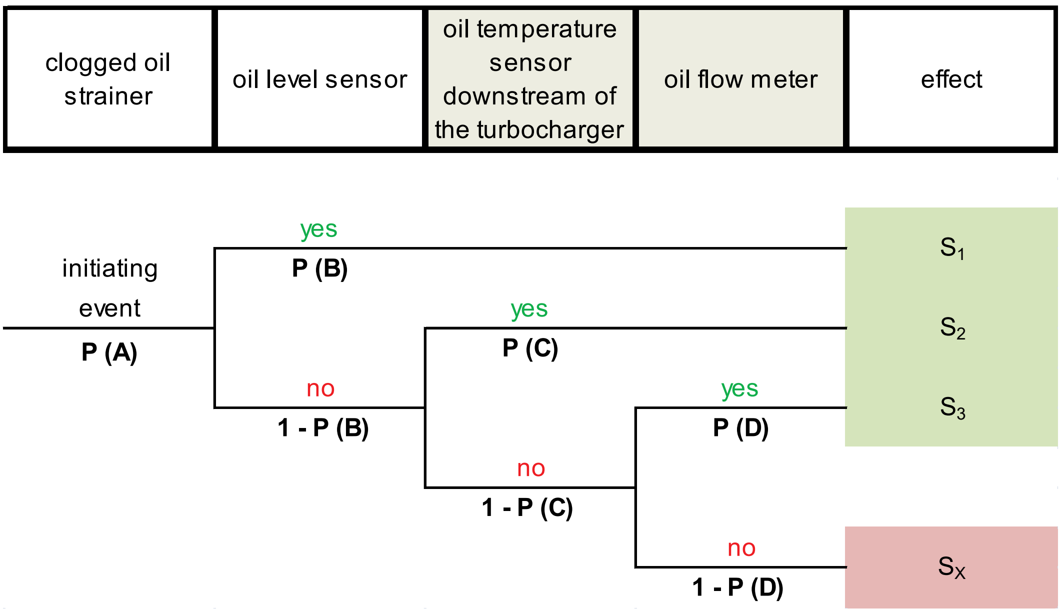

Fig. 3. Event Tree for the initiating event "clogged oil strainer" taking into account the proposed additional barriers

Probabilities in qualitative terms are analogous to the analyses carried out before introducing changes and equal (respectively): for the initiating event $P(A)' = 0.1$, for the event at barrier B: $P(B)' = 0.1$; and the proposed $P(C)' = 0.9$;

$P(D)' = 0.9$. Numerical values of probabilities of occurrence of a given type of effects in quantitative terms are as follows:

$$P(S_1)' = 0.01, \quad P(S_2)' = 0.081, \quad P(S_2)' = 0.0081. \tag{5}$$

The probability of occurrence of a critical event is equal to:

$$P(S_X)' = 0.0009. \tag{6}$$

5. Summary

Based on the tests performed on the test bench and based on the Event Tree Analysis, the authors have confirmed that the introduction of additional safety barriers in the form of sensors renders measurable results. On one hand, the cost of implementation of additional sensors in a turbocharger may have impact on its price. On the other hand, given the benefits related to, for example, the engine environmental performance, the proposal described in this article appears to be well substantiated. In the total balance, the proposal results in a significant reduction of the engine environmental impact (exhaust emissions throughout the engine life cycle) caused by the occurrence of a critical event, at the same time reducing the costs of component renewal and search for the cause of the malfunction. [5, 6]. The model has shown that the probability of occurrence of a critical event was significantly reduced (Tab. 1).

Tab. 1. Probability of occurrence of a critical event

Initiating event	Probability of occurrence of a critical event P(SX)		Indicator of improvement of the system reliability
	Without additional barriers	With the proposed barriers	
Clogged oil strainer	0.045	0.00045	100

The authors attempted to analyse the damage in turbochargers with certain expert assumptions that can be freely modified by acquiring the input data from research results or service repair statistics. Given the fact that the estimated data are debatable, the proposed monitoring solutions present clear relations having a positive impact on the component durability and reliability. The ETA method transparently determines the mutual connections between the functioning and unworthiness of safety systems. These systems should be allowed for already on the stage of component design.

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