Parameter-based System-FMEA for Turbocharger Validation

Using a new method of a parameter-based System Failure Mode and Effects Analysis designed by consulting company Life Cycle Engineers, MAN Diesel & Turbo can precisely evaluate potential turbocharger risks automatically and rapidly derive validation plans. The new method is proving invaluable in turbocharger development, enabling improved risk assessment and better communication with the customer.

BACKGROUND

Augsburg-based MAN Diesel & Turbo SE has traditionally designed and manufactured its own range of turbochargers for its low and medium speed, diesel, gas and dual-fuel engines. Now, with its decision to build high speed engines, turbochargers for this type of engine have been added to the portfolio. An example of the 175SD high speed engine is shown in FIGURE 1.

As a result, not only have production volumes increased, but also requirements concerning the duration of development projects. As part of this change, product risk assessment and the overall assessment of new projects has been modified to ensure more systematic, objective and comprehensive evaluations.

The new procedures take account of the fact that turbochargers are exposed to high mechanical and thermal loads, so that even the smallest failures might have a serious impact, and that high-speed engines, like those used in locomotives or various earthmoving machines, have completely different load cycles compared to the more continuous duty expected of low and medium speed engines used in ships and power plants.

COMPONENT OR FUNCTION-RELATED

The Failure Mode and Effects Analysis (FMEA) method has become vital as a central means of preventive error detection. Using FMEA, potential failures can be reliably identified in the very early stages of product development and possible actions defined. This approach contrasts with the situation in many companies, where FMEA studies are still considered a back-up and often only performed as late as possible in the product development process or when the customer requests it.

Another disadvantage of the conventional way of using FMEA is that it often relates to components, not functions and thus a thorough analysis can only be performed if all the parts of a system have already been designed in detail. At MAN risk analysis was already performed based on product functions. In this approach the individual functions of a turbocharger are first hierarchically structured and then associated with their components.

Generally, for each risk a so-called “risk priority number” (RPN) is defined. This value is known to be a product of the probability of the occurrence of a failure, its importance or its effects and the probability of its detection. Various guidelines such as the recommendations of Germany’s VDA or VDMA engineers associations describe this procedure in more detail.

PARAMETER-BASED SYSTEM-FMEA

In 2014 MAN Diesel & Turbo sought the support of consulting company Life Cycle Engineers, based in Mainz, Germany. The company had already further developed a traditional component-based FMEA method for the automotive industry several years ago and since then had successfully adapted it to a wide range of customer requirements.

The starting point of the cooperation was a situation where the lead-time for an initial FMEA investigation for a new turbocharger application engineering project was about a week. Moreover, these investigations were not executed on a common basis, but performed individually. To detect and evaluate potential failures much earlier and more systematically, this high expenditure in time and effort had to be reduced.

Together the project team defined the goal of unifying the risk analysis with the help of a parameter-based System-FMEA through a standardised, automated approach to assure high comparability. FIGURE 2 shows a comparison between the earlier and the newly adopted FMEA procedures. The parameters to be defined should be in line with the requirements, i.e. the concrete application of the turbocharger.

Further, all known risks as well as the testing and prevention measures envisaged should be linked to each other so that, as a result, the validation plan should be compiled automatically.

COMPLETE PERFORMANCE DESCRIPTION

In a first step, for the product group TCR radial turbine turbochargers (see FIGURE 3) the different operating conditions of an application, such as a locomotive diesel engine, were compiled in a parameter list. This set of
about 100 values fully describes the functional performance of an application – including, for example, the load cycles, the cooling water temperature or the charge air pressure.

A small selection of such major parameters or the charge air pressure.

load cycles, the cooling water temperature – including, for example, the maximum value range of fault-free operation. This approach offers the advantage that, due to the documented customer specifications, the actual value of the parameters of a new application can be compared immediately with these standard values. An overview of the methodology is shown in FIGURE 3.

Essentially, therefore, a concrete statement is available at any time and for each parameter. The parameters are then linked to the individual functions and components of the turboccharger: Using a weighting mechanism, associated to this link, the primary influence of the parameter – for example an increase in charge air pressure – the specific risks and the influence to the overall risk profile can be ascertained.

CAPTURING ALL RISKS

An important next milestone in the automated System-FMEA procedure was to gather all known risks independent of the turboccharger’s specific application. Unfortunately, this knowledge was previously decentralised and stored on a project or customer-specific basis, in both the memories and files of employees. In the past, this unstructured distribution of knowledge occasionally led to failures in individual investigations, so that employees had to deal either with unnecessary questions or, in the worst case, overlooked potential risks.

In the next step, the new maximum list of all risks was linked to the identified parameters and by adjusting the parameters to the actual values of a given application, it was possible to reduce the list of all potential risks automatically, leaving only the relevant ones.

FIGURE 3 Radial turbocchargers from MAN’s TCR range used on the company’s annular and medium bore, medium and high speed engines have benefitted from a sophisticated new System-FMEA procedure (© MAN Diesel & Turbo)
**CONTEMPORARY ENGINE DEVELOPMENT**

**Risk**

**TCR turbocharger**

*Function tree, experience, a significant increase in RPN. If the modified parameter value parameters is bound to change the parameters is bound to change the risk, right up to the more complex calculations for deriving a validation plan based on the valid ranges of experience, which now lists all the measures which are necessary to clarify the relevant risks. If necessary, the tool also grants additional views, for example which parameters have the greatest influence on the risks, which are the most vulnerable components or which components or functions are related to a load cycle test on the component test bench. The total risk profiles of different applications can thus be compared with each other.*

**Expansion of the tool**

Initially, the parameter-based System-FMEA was developed for the TCR range of turbochargers with radial flow turbines for the company’s new high speed engines. This already offers the possibility of rapidly checking proven applications with modified parameter values based on customer requests.

In a subsequent step, new applications were integrated into the tool. For these, only limited or, in some cases, no complete data based on real operating experience is available. Basically, however, this experience is always based on statistically proven assessment methods and their underlying database is successively extended to apply the aforementioned calculations which influence the RPN.

**Conclusion**

In summary, the new method developed together with consulting company Life Cycle Engineers has become an innovative and flexible tool which enables a significant improvement in the quality of the analysis of risks. The significant reduction in lead times – from about one week to one day – combined with the automatic product adaptation to new customer requests and the improved quality of analysis, have resulted in a thorough acceptance of the method by development and application engineers. In addition, the consequent improvement in communication leads to a substantial increase in the efficiency of their work. Finally, overall there is the important additional benefit that an increased number of projects can be undertaken during a given period.

**Automatic systematic validation plan**

To validate a risk identified in this way, the necessary checks must be carried out in a development project. Thus, a so-called master validation plan was created, similar to the maximum list of risks described above, which is also independent from the type of turbocharger application. In a first step, all relevant prevention and testing measures were collected together and all measures then related to the appropriate risks.

Since a modified parameter can affect multiple functions or components, the tool allows different points of view, for example which parameters have the greatest influence on the risks, which are the most vulnerable components or which components or functions are related to a load cycle test on the component test bench. The total risk profiles of different applications can thus be compared with each other.

Finally, the turbocharger user automatically receives a full validation plan, which now lists all the measures which are necessary to clarify the relevant risks. If necessary, the tool also grants additional views, for example which parameters have the greatest influence on the risks, which are the most vulnerable components or which components or functions are related to a load cycle test on the component test bench. The total risk profiles of different applications can thus be compared with each other.

**Expanding use of the tool**

Initially, the parameter-based System-FMEA was developed for the TCR range of turbochargers with radial flow turbines for the company’s new high speed engines. This already offers the possibility of rapidly checking proven applications with modified parameter values based on customer requests.

In a subsequent step, new applications were integrated into the tool. For these, only limited or, in some cases, no complete data based on real operating experience is available. Basically, however, this experience is always based on statistically proven assessment methods and their underlying database is successively extended to apply the aforementioned calculations which influence the RPN. The third task field will extend the tool to other product lines and variants such as turbochargers with axial flow turbines. And, last but not least, MAN had already begun to use the potentials of its parameter-based System-FMEA capabilities to achieve innovative product development. In this area, the tool has become an essential element for identifying potential risks in the very early stages of product development and to specifically avoid those risks by the use of tests and simulations.

The new parameter-based System-FMEA, with parameter lists which are always fully described, has also intensified communication with the customer, at a level of clarity which was not always possible in the past. During the processing of a new customer request, the standard values of the parameters for a specific application are assessed and modified as necessary in the way described above. Customers are, thus, challenged to clearly set out their requirements, to keep them up-to-date and to reconﬁrm them if needed. In this way, the process of reconciling development to customer requests is always documented. Moreover, MAN is now in a position to assume an increasing role as an adviser and know-how supplier towards the customer. Staff address design-relevant suggestions in a proactive rather than a reactive way. A common technical understanding with the customer is now available as a result of the in-depth communication which takes place.

**Conclusion**

In summary, the new method developed together with consulting company Life Cycle Engineers has become an innovative and flexible tool which enables a significant improvement in the quality of the analysis of risks. The significant reduction in lead times – from about one week to one day – combined with the automatic product adaptation to new customer requests and the improved quality of analysis, have resulted in a thorough acceptance of the method by development and application engineers. In addition, the consequent improvement in communication leads to a substantial increase in the efficiency of their work. Finally, overall there is the important additional benefit that an increased number of projects can be undertaken during a given period.