The impact of a high strength E-actuator on the turbocharger

Management summary

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Problem statement

During testing of a new turbocharger (T/C), several samples showed evidence of local contact between; the compressor wheel(C/W) and compressor cover (C/C); the turbine wheel (T/W) and turbine housing (T/H). also there was damage on other components that holds investigations had already been carried out to determine the root cause of the problems. No single cause was found, but the electric actuator (EACT) could be related to both failures.

Literature research

The literature research can be subdivided into two parts, specific knowledge of the T/C and general effects of increased temperature

Specific T/C knowledge

First an analysis was made of a theoretical approach to determine torques on the T/C already available at MTEE. This provided a base to analyse how the EACT influences the T/C. Second there is shaft motion, which about radial movement of the C/W and T/W due to operation. The use of floating bearings in the cartridge allows for this movement. Third, tip clearance. Tip clearance is the distance between a wheel and its housing. A different tip clearance is specified for each T/C. Tip clearance can be measured in cold condition and is bound to change during operation.

Effects of increased temperature

The temperature of all T/C components increases during operation. Within the scope of this project there are two important effects. The first effect is that an increase in temperature will reduce the yield and tensile strength of the material. The reduction of these properties will lead to a lower force necessary to cause plastic deformation and failure respectively. Meaning that a certain force that will not cause failure at room temperature can cause failure during T/C operation. The second effect is thermal growth of the material. Material will expand as the temperature rises. This effect is most important in locations that contain small tolerances, like tip clearance and connections between components.

Results

First an effort was made to determine what change to the linkage kinematics would have the most influence on the forces exerted by the actuator. It was discovered that the angle between the T/C centerline and the EACT leverplate (angle α) was the most influential factor. The other angles β and γ change as well, but have little impact on the forces.

Second more research was conducted as to why the forces of the actuator were as high as they were. From test results previously gained by MTEE, it became clear that the ECU also played a role in the behaviour of the actuator force. Additionally it was proposed that the actuator force has to be high because there are many variables at play that cannot be determined.

Third a list was made of all components that are influenced by the EACT. Subsequently a list could be made of which components may contribute to causing failure. The most important components are:

- All components of the EACT linkage system. All moving components are prone to wear during T/C lifetime. Wear will alter the linkage system, modifiying the forces exerted by the EACT and thus accelerating failure.
- The C/C and T/H. These components are subject to deformation as a result of changing temperatures and external forces. External forces include forces of the EACT, but also forces caused by piping connections. Deformation of the C/C and T/H can also result in deformation of the shroud, which can reduce tip clearance.

Fourth a calculation was made to determine how various influences modify the kinematics of the EACT linkage and how the force exerted by the EACT changes. A division was made between effects that occur during T/C operation and effects occuring during T/C lifetime. Operational effects include the deformation of the linkplate and thermal growth of the T/H, bearing housing (B/H) and C/C. Lifetime effects include rotation of the B/H and C/C in relation to the T/H, tilting of the B/H in the T/H. wear of the linkplate connections. Using the four bar linkage model, it was determined that the sum of the two operational effects has almost no effect. The wear of the linkage has significant influence in determining the α and thus the forces exerted by the EACT.

Fifth calculations were made to determine what torques the EACT caused on the T/C. The bending torque and twisting torque were calculated based on the forces calculated in the previous section.

Sixth a summation of the effects that directly influence tip clearance of the T/W and C/W. The following effects were taken into account:

- Thermal growth of the wheels (growth of the T/W is an approximation)
- Growth of the wheels due to centrifugal forces (growth of the T/W is an approximation)
- Shaft motion
- Deformation of the shroud of the C/C and T/H
- Misalignment of the B/H and C/C
- Tilting of the B/H in the T/H

It was determined that hitting due to the above causes was plausible.

Discussion

In the discussion a few insightful remarks were made.

- Deformation of the C/C according to the simulations does not conform with the location of hitting on test samples.
- The shroud deformation purely influenced by thermal expansion of the T/H suggests that all tested samples should have hitting, which is not the case.
- The link of between the EACT forces and the T/H&B/H tilting is dubious. Likewise for the C/C&B/H misaligment.

Recommendations

MTEE is recommended to conduct the following actions:

- Investigate the influence of other external factors in causing deformation of the components.
- Investigate if the V-clamp deformation as a result of EACT forces and temperature increase.
- Validate the linkage kinematics model
- Determine V-clamp force distribution
- Use the linkage model to determine the worst case scenario for the linkage, which can be used for an endurance test.