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How We Develop a Heavy-Duty Transmission

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Abstract

Aeolus EQ-140 is one of the mass producing medium range heavy duty trucks in China. Some defects on its transmission have been detected. And their improving measures have come out in satisfactory results: (1) By improving the material of inner ring, the life of the synchronizer has increased by 100 times compared with its first prototype in 1969. (2) The fatigue life of 2nd speed gear has gone up by 10 times, with adopting more generous tooth root fillet radius and shot peening the tooth roots.

1. Foreword

The performance and service life of a transmission have great influence on an automobile. How to improve the performance of a transmission and how to prolong its service life? Those problems are of interest to all automobile engineers.

Even if you have had a perfectly designed transmission, there would be some failure occured in actual service. The causes are as follows:

(1) The objective differences between parameters used in theoretical design and calculation and the actual service.

(2) The unstable functions in the production processes.

(3) The undeveloped potential in the design and manufacture of transmission.

To solve a problem occured in the existing transmission is sometimes even more difficult than to design a new type of transmission.

Aeolus EQ-140 is one of the medium range heavy duty trucks in China. Its transmission consists of five forward speed gears and one reverse. The fifth speed gear is a direct drive. There are and 5th speed gears. The max. output torque of the transmission is 2800Nm and the net weight is 86 kg. It's a typical manual mechanical transmission, which is highly praised by all customers.

There had been some shortcomings on this transmission, for example, poor performance and short service life of the synchronizer, early bending fatigue damage on 2nd speed gear, etc. In consideration of the above mentioned three causes, we have taken many measures. At last, satisfactory results have been obtained through continuous efforts.

2. Synchronizer

To use a transmission with a poor performance and short service life synchronizer is worse than to use one without synchronizer. The thread on the inner ring of the prototype synchronizer produced in 1969 was worn out just after running about 1000 km. And after progressive improvement the service life of the synchronizer has been prolonged from 10,000, 20,000, 30,000, 50,000, 80,000, 100,000, to about 150,000 km. To reach this value many difficulties have been overcome in order to meet the frequent speed changing requirements brought about

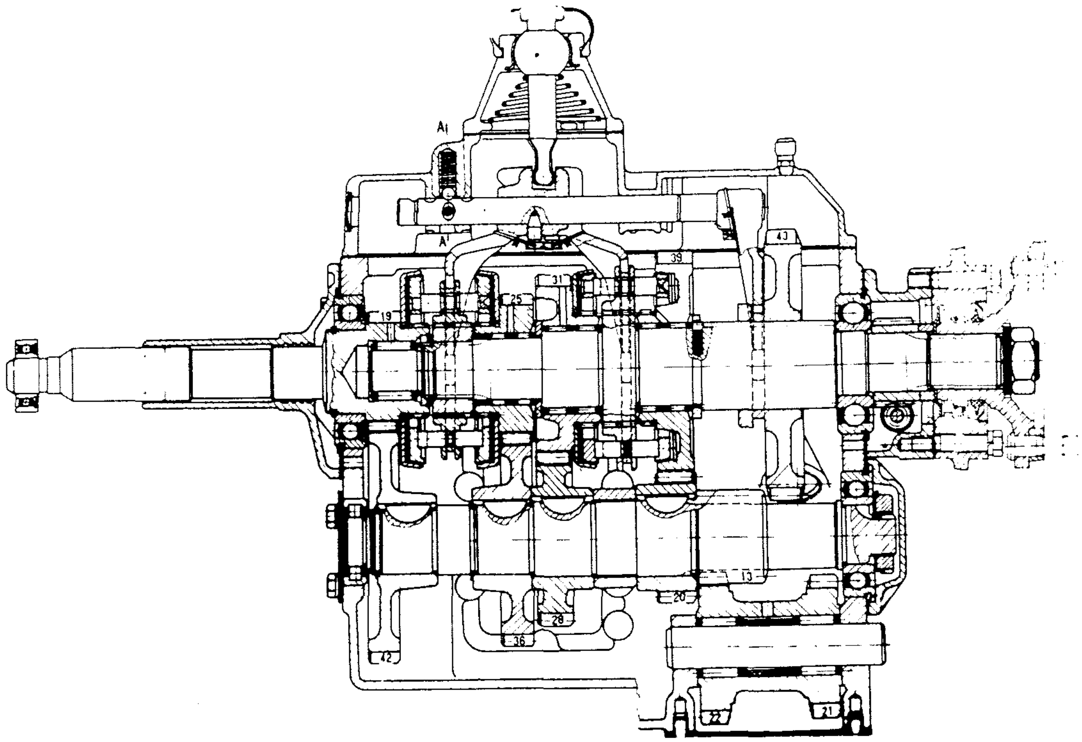


Fig. 1 EQ140 transmission assembly

How to improve the service life and performance of the synchronizer?

2. 1. Improve the antiwear performance of synchronizer inner ring.

The original inner ring was made of aluminum alloy to save copper. For this construction material, we have experimented first with eutectic aluminum silicon alloy made in permanent mould or / die casting, then with the hypereutectic aluminum silicon alloy treated with anodic oxidation under low temperature. The service life of both had been prolonged, but the effects were still not good enough. Especially the latter, though it had a longer service life, the machinability and the uniformity of quality were poor. At last the inner ring had to be made of copper.

In the using of copper alloy, manganese brass was found the best after a series of tests, which is suitable for die casting and is of high strength (tensile strength $600N/mm^2$) and good antiwear characteristics (HB 150). The wear-resistance of this material has been proved through years of practice and the service life of inner ring has been greatly prolonged.

2. 2. Improve the design of synchronizer

(1) Redesign a new device for locating the radial position of the inner ring to make it concentric with the sliding sleeve. Thus when selecting speed gears, the inner ring can be in contact with the outer stop ring concentrically and the friction moment can be built up at once for easy synchromeshing and also the inner ring does not touch with the outer stop ring to prevent meaningless partial wear when it is in neutral postition.

(2) Improve the axial positioning of the synchronizer sliding sleeve to make the location more precise and the shift feeling more clear. The difference between the original and the improved synchronizer is shown in Fig. 2.

(3) Reexamine the clearances of the synchronizer

As shown in Fig. 3, $\delta 1$ is the axial clearance between the inner ring (at neutral) and the outer stop ring;

$\delta 2$ is the clearance for wear between the end faces of the outer stop ring and the **inner ring;**

$\delta 3$ is the clearance between the sliding sleeve and the dog teeth end.

These three clearance values and the relationship among them are very important to ensure the performance and

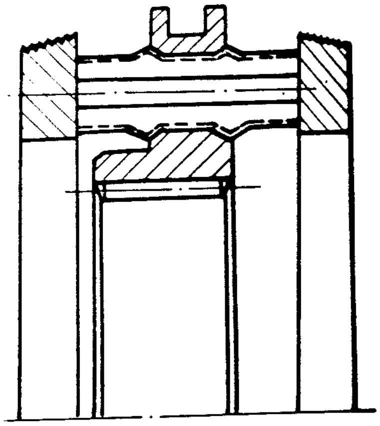
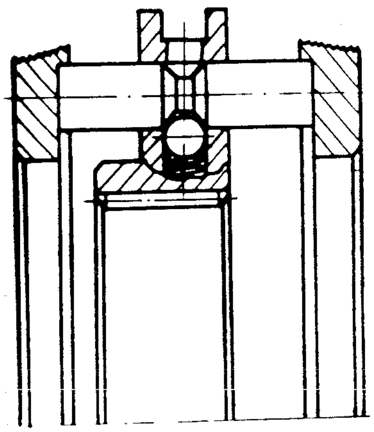


Fig. 2a Thin-wall spring pin
for axial positioning
(before improvement)



2b Locating pin for axial
& radial positioning
(after improvement)

$\delta 1$ is effected by the design value and the manufacture precision.

$\delta 2$ is determined by the thread depth and the angle of the conical surface of the inner ring, as well as the friction coefficient which can still keep the synchronizer working in good order when the thread is worn out to a certain degree.

$\delta 3$ is important to keep normal working of synchronizer and to exploit its potential service life fully.

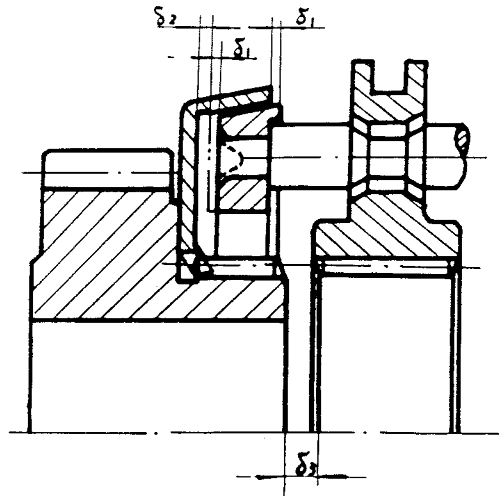
$\delta 1$ and $\delta 3$ are affected by the manufacturing precision.

That is why the accuracy of the axial dimensions for transmission with synchronizer is much higher than that without synchronizer.

If the clearance $\delta 1$ (in neutral) is too small, the synchronizer would be burnt.

If the clearance $\delta 2$ is too small, the synchronizer can not work any more even if the inner ring is only worn out slightly.

If the clearance $\delta 3$ between the two



$$\delta_3 \geqslant \delta_1 + \delta_2$$

Fig. 3 Three important clearances
and their relationship of
pin type synchronizer

conical surfaces of the synchronizer can not engage due to the tooth ends strike against each other, so that the synchronizer cease to be effective.

After modifying the design and correcting the clearances of the synchronizer, the performance of selecting speed gear and the service life of the synchronizer have been greatly improved.

2. 3. Improve the rigidity of the shift fork

The shift fork has been redesigned, that is, its legs were thickened (toe thickness from 6mm to 8mm) and a reinforcing rib was added to increase its section factor and so the rigidity of the shift fork, preventing from changing the relationship among those clearances of the synchronizer due to the deformation of the shift fork. So the synchronizer can maintain its designed function.

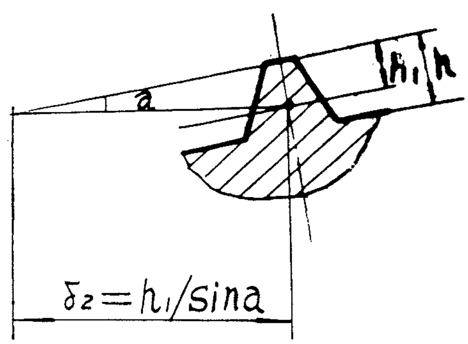


Fig. 4 The relationship between the
thread depth of inner ring and

2. 4. Increase the interference of fitting dimensions between the lock pin and the inner ring to ensure that the synchronizer would not be loosened during operation. After improvement, the friction moment between each lock pin and the hole of inner ring is about 3 - 5 times more than previously obtained for better reliability of the synchronizer.

2. 5. Another measure is to increase the surface finish of the outer stop ring to improve the wearability of the inner ring. The roughness should be improved from Ra 0.32 to Ra 0.16. Care must be taken for inspecting the out of roundness of the outer stop ring.

2. 6. The locking face angle of the locking pin and of the sliding sleeve should be strictly the same and all the corresponding locking faces should contact each other soundly in operation. The position accuracy of the three holes for fitting the locking pins on the inner ring and on the sliding sleeve has been raised to keep the normal working of the synchronizer and to insure easy shifting.

After the improvements mentioned above on the synchronizer, its service life has been increased progressively to 150,000 km, about 100 times more than that of 1969's production.

3. Early bending fatigue damage on 2nd speed gear

The 2nd speed gear of transmission is not likely to have bending fatigue damage in general. But during the service test of EQ 140 truck in mountainous area, the 2nd speed driven gear has been broken several times after running about 35,000 km due to bending fatigue. At this time the proportion of fully laden mileage of the truck is 83.1 %, in which there is 37 % running in mountainous area and 74.7 % running with trailer. After checking over the material and heat treatment of the gear, no abnormal case was found. Bending stress fatigue damage occured repeatedly in such a small mileage was not regular. So it was not fit for mass production of EQ 140 truck.

How the bending fatigue life of 2nd speed gear is improved?

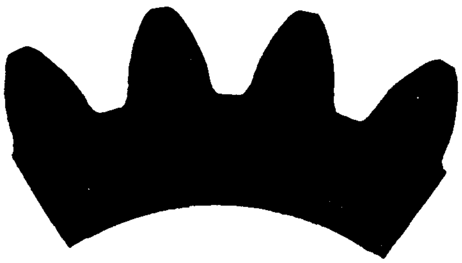
condition

Running an EQ 140 truck equipped with relative testing instruments in the above mentioned area on various road and under various loading, measure the actual service load and proportional mileage for each selected speed of transmission. After data processing, the equivalent service load and the corresponding frequency have been obtained. These may be used as the basis to assess the result of the bench test. The testing truck was driven by the same driver on the same road and with the same load to make the testing condition close to the previous running.

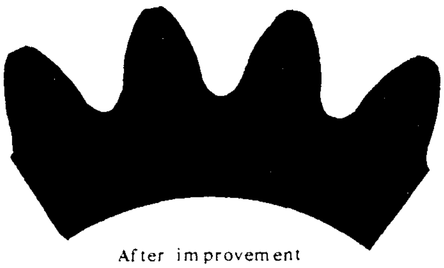
Converting the measuring result into the load cycles at the max. engine torque of 360Nm, 35,000 km is equivalent to $(0.3 - 0.4) \times 10^6$ cycles, so the cycles for EQ 140 truck running 200,000 km in this area should be $(1.7 - 2.0) \times 10^6$.

3. 2. The way to attain longer bending fatigue life of 2nd speed gear

There are many factors influencing the bending fatifue life of gear. It is most important to find out the main factor, which should be effective and with little cost. After carefully observing the damaged sample, with the author's experience, it is recognized that the main cause of the early damage of 2nd speed gear is the result of too much stress concentration due to the tooth root fillet radius too small. We decided to increase this radius as much as possible and make the bottom of tooth space to approximately semi-circular to decrease the stress concentration factor, that is, by means of changing the tooth tip of hob from double arcs to a single arc, altering the radius of tooth root from 0.8 mm to 1.5 mm, while keeping the starting point of involute tooth meshing constant. In this way, the stress concentration factor will be significantly reduced, since the tooth bottom is an even semi-circular arc. To increase the fillet radius, the advantages are more than the disadvantages for bending strength, though the whole depth of tooth is slightly increased. The attention of such a matter has not been paid widely in our country especially for the case specifies that the fillet radius of base rack is 0.25M. Because it is not strictly controlled as a factor effecting strength, the actual fillet radius of the gear tooth is less than this value. Fig. 5 shows the tooth sections of the 2nd speed drive gear before and after improvement.



Before improvement



After improvement

Fig. 5 The tooth sections of 2nd speed drive gear

In order to further decrease the tensile stress of the tooth root, it is decided to raise the residual compressive stress of the tooth root by shot peening on the gear. As a result the magnitude of the tensile stress in service is reduced and the bending fatigue life of the gear is prolonged.

Shot peening is conducted on a self-made shot peening machine. The root is vertical to the direction of the shot peening, and the gear rotates automatically.

The peening shot is made of tempered cast steel (HRC 30 - 44).

Shot diameter 0.6 - 0.8 mm
Shot speed 61m/sec
Shot peening intensity
Almen 0.15 - 0.16C

It is necessary to prove whether this measure is effective. Several groups of samples have been tested to compare their effects, with using larger module gears and stub tooth gears.

About 1,000 hrs of comparative tests have been carried out on a close under the max. engine torque. And the test results verified that the service life of the 2nd speed gear, which the fillet radius was increased and the root fillet shot peened, is the longest. Several pairs of such gears were tested further to 4×10^6 cycles (driven gear) without failure, the service life was raised up to 10 times compared with that of the unimproved 2nd speed gear. It can ensure 350,000 km for EQ 140 truck transmission running in the mountain areas. This confirms the judgement is correct and the measure taken is effective, and the problem is solved within the allotted time.

Since the improved 2nd speed gear was put into production in 1975, no bending fatigue damage has ever happened in service.

It is evident that this improvement is an efficient and economic way to open up the potential of the gear design and manufacture and to solve the problems met in the service of the transmission without changing the gear basic specifications, material and the existing process. Only new hobs have to be procured.

The EQ 140 transmission is still being improved, with the aims at raising its load capacity comprehensively in order to make it fit to larger torque engines for trucks with more GVW. This article is just a brief description of a few examples in our work for improvement.