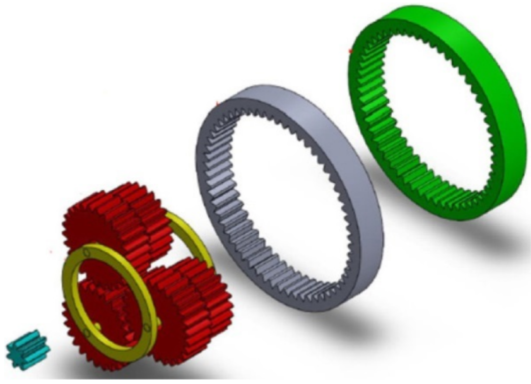
Bilateral Gear that Enable Downsizing of Drive Unit for Mobile Vehicle



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With the progress of electrification, demand for geared motors consisting of a high-speed motor and a reduction gear is increasing. In particular, there is a strong need for downsizing drive units for mobility applications such as automobiles, the market for which is expected to grow, so a first-mover advantage can be gained by developing a transmission unit that is both downsizing and large-reduction ratio. In this research, we focused on the bilateral gear developed by Yokohama National University as a new large-reduction-ratio mechanism that enables the significant downsizing of drive units and designed and manufactured a 50kW prototype gear for mobility applications. We also conducted a load test to verify its power transmission efficiency, temperature and vibration. This report gives an overview of the prototype bilateral gear and the results of the load test.

1. Introduction

In order to downsize drive units consisting of a motor and a reduction gear, it is effective to combine a compact, large-gear-ratio reduction gear with a high-speed motor. However, the reduction ratio attained with general gears is about four to five at most and obtaining a large gear ratio requires a reduction gear with a multi-stage configuration, which results in the problem of a larger size. In addition, the power transmission efficiency of conventional large-reduction-ratio mechanisms such as HarmonicDrive® units and Cyclo® Drive units is not very high, so it is difficult to apply them to the applications. In this research, we focused on the bilateral gear(1) developed by Yokohama National University. This gear system is a mechanism that enables a large reduction ratio by combining a planetary gear, which has excellent efficiency and reliability, with internal gears of different specifications and is expected to achieve downsizing and a large reduction ratio as well as high efficiency. However, bilateral gears developed so far are for use in robots, so their output capacity is as low as 1 kW or less and they could not be applied to mobility applications such as automobiles that require a gear that can deal with greater output of several tens of kW or more and faster rotation speeds of 10,000 rpm or more. Therefore, Mitsubishi Heavy Industries, Ltd. (MHI) designed and manufactured a 50 kW, 17,800 rpm prototype bilateral gear assuming its use in mobility applications and verified it by conducting a load test.

2. Configuration of bilateral gear

Figure 1 shows the structure of the bilateral gear. This structure is basically similar to that of a two-stage planetary gear, but consists of an input sun gear, two planetary gears 1 and 2 arranged coaxially, a fixed internal gear and an output internal gear. Planetary gear 1 meshes with the fixed internal gear and planetary gear 2 meshes with the output internal gear.

Figure 2 shows the transmission principle of a bilateral gear. In the case of a conventional planetary gear system, the internal gear is fixed and the carrier serves as the output shaft. In the case of a bilateral gear, however, the internal gear is divided into two, one of which is fixed and the

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other serves as the output shaft. Any gear ratio can be obtained by changing the number of teeth of the planetary gears that mesh with the two internal gears. Based on the principle described above, the bilateral gear changes speed in two stages, which can attain a large reduction ratio.

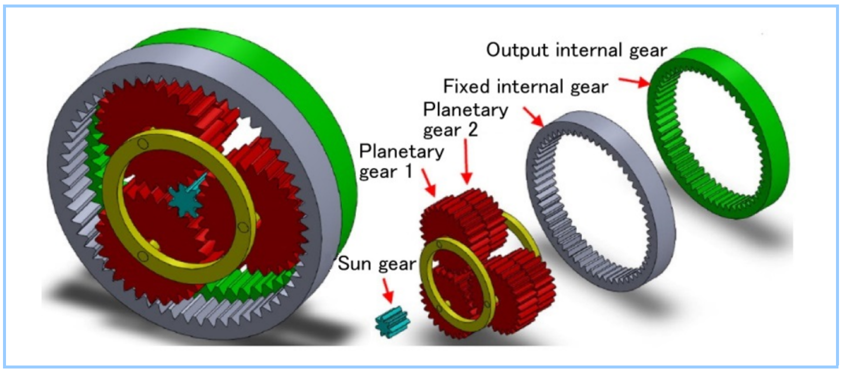

Figure 1 Structure of bilateral gear
A bilateral gear has a structure similar to that of a two-stage planetary gear basically, but consists of an input sun gear, two planetary gears arranged coaxially, a fixed internal gear and an output internal gear.

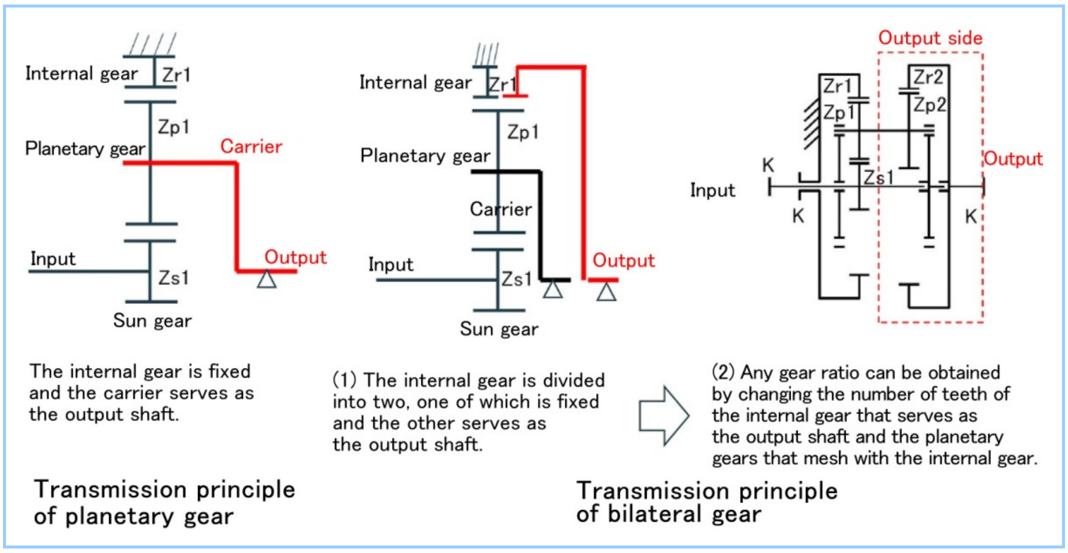

Figure 2 Comparison of transmission principles of bilateral gear and conventional planetary gear
The bilateral gear has a structure that enables a large reduction ratio by combining a planetary gear and internal gears with different specifications.

3. Design of bilateral gear

The bilateral gear was designed based on the procedure shown in **Figure 3**.

First, we evaluated the relationship between the size and reduction ratio of drive units consisting of a motor and reduction gear to select a reduction ratio effective in reducing the size. **Figure 4** shows the result of calculating the relationship between the size and reduction ratio of drive units for the output of 50 kW and the output shaft speed of 500 rpm, which are the conditions for the product used as a sample in this research. As shown in this figure, the larger the reduction ratio, the more reduced the size, but when the reduction ratio is 30 or more, the downsizing effect becomes smaller. Therefore, we selected a reduction ratio of 30 to 40.

Next, we selected the number of teeth of each gear so as to obtain the reduction ratio selected above and calculated the addendum modification coefficient and helix angle of each gear with which the power transmission efficiency was maximized, using the gear specification selection program(1) jointly developed with Yokohama National University. Furthermore, we performed strength analysis of the derived specifications using the gear strength analysis method(2) developed by our company to select tooth widths and modules that satisfied the fatigue strength requirement.

Table 1 lists the finally selected gear specifications of the bilateral gear, which resulted in a reduction ratio of 35.8 and an input shaft speed of 17,800 rpm. We calculated the load acting on each shaft based on the gear specifications shown in Table 1 and the output torque to design the bearing specifications that satisfy the required life of the product and the detailed structure of the carrier, housing, etc.

Figure 5 is a structural diagram of the prototype bilateral gear designed based on the above procedure.

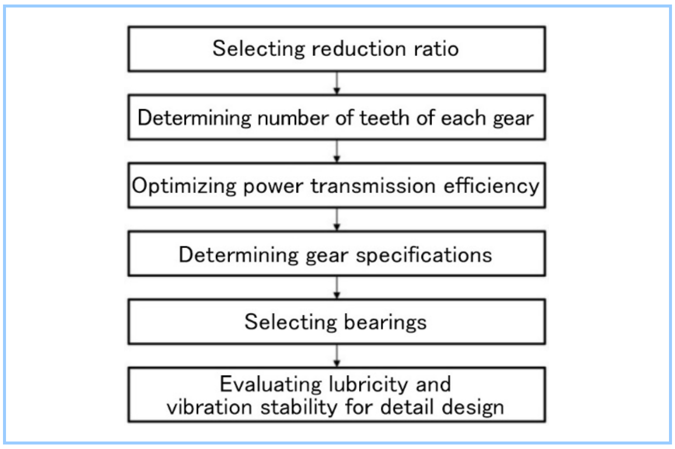

Figure 3 Design procedure of bilateral gear
The prototype bilateral gear was designed according to this procedure.

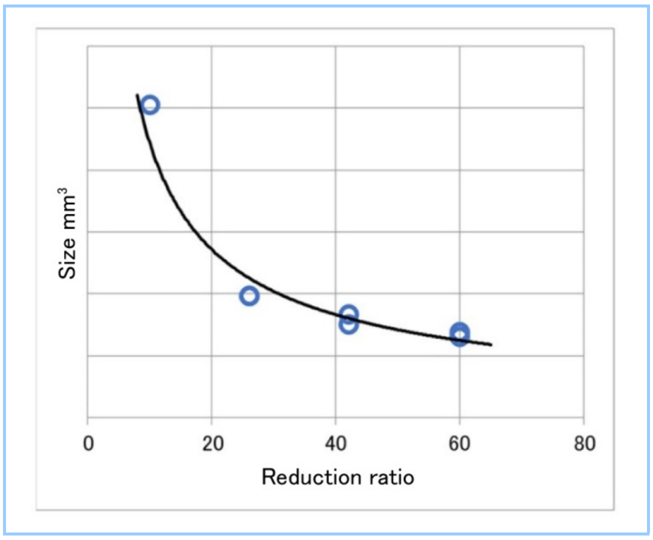

Figure 4 Relationship between size and reduction ratio of drive units
The larger reduction ratio, the more reduced the size, but when the reduction ratio is 30 or more, the downsizing effect becomes smaller.

Table 1 Gear specifications of prototype bilateral gear

	Sun gear	Planetary gear 1	Fixed internal gear	Planetary gear 2	Output internal gear
Number of teeth	23	47	117	35	105
Module	1.5			1.5	
Tooth width	25 mm			38 mm	

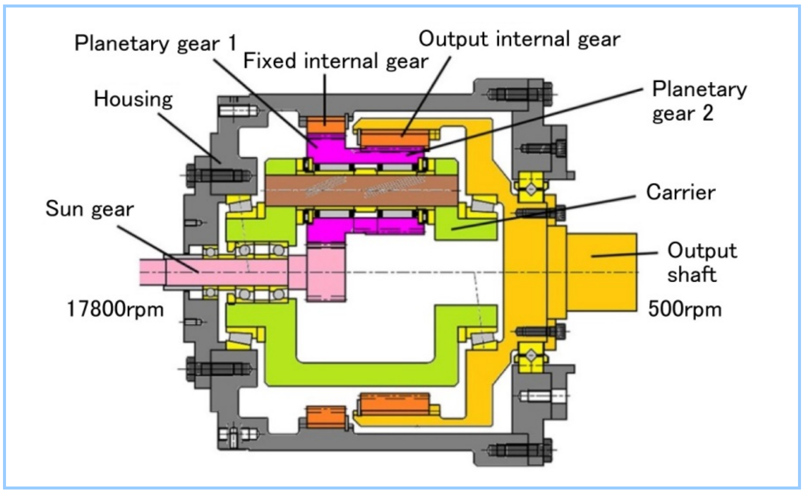

Figure 5 Structure of prototype bilateral gear
This figure shows the structure of the 50 kW prototype bilateral gear.

4. Verification with load test

We manufactured the bilateral gear described above and verified whether its expected performance can be obtained by conducting a load test. **Figure 6** shows the configuration of the load test equipment. The rotation generated by the motor was increased through the planetary speed increasing unit and the belt-type speed increasing unit to 17,800 rpm at the input shaft of the bilateral gear and load torque was applied to the output shaft of the bilateral gear by using the brake. In this test, the items shown in **Table 2** were measured in order to identify reliability- and performance-related issues for applying the bilateral gear to products.

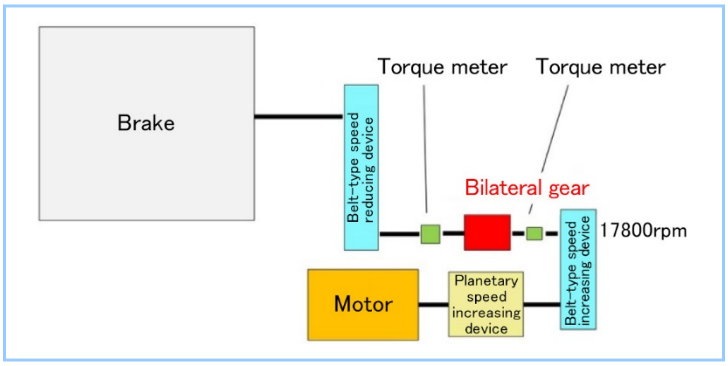

Figure 6 Configuration of bilateral gear load test equipment
The rotation generated by the motor was increased through the planetary speed increasing device and the belt-type speed increasing device to 17,800 rpm at the input shaft of the bilateral gear system and load torque was applied to the output shaft of the bilateral gear by using the brake.

Table 2 Measurement items of prototype bilateral gear

List of measurement items
(1) Torque input into sun gear shaft of bilateral gear
(2) Torque output from output shaft of bilateral gear
(3) Temperature of outer peripheral surface of fixed internal gear
(4) Vibration velocity of housing

Figure 7 compares the experimental and predicted (calculated) values of the efficiency of the bilateral gear. In this figure, the horizontal axis represents the load (%) and the vertical axis the efficiency (%). The efficiency was calculated by using the torque values input to the sun gear shaft and output from the output shaft. The power loss at the gears was calculated using the tool developed by Yokohama National University and the power loss at the bearings was calculated with reference to materials prepared by NSK[3]. As shown in the figure, it was confirmed that the experimental and calculated values of the efficiency almost agreed. In addition, it was indicated by the measurement that the efficiency of the bilateral gear was 15% or more higher than that of a

HarmonicDrive® unit.

Figure 8 shows the measurement results of the first-stage internal gear temperature. In this figure, the temperature change when the load was increased with the rotation speed maintained at 17800 rpm is indicated. The horizontal axis of this graph represents the load (%) and the vertical axis the temperature (°C). The correlation between temperature and output was almost linear and no abnormal temperature rise was seen.

The vibration of the housing was 1.8 mm/s, which was sufficiently smaller than 4 mm/s of the vibration tolerance specified by ISO[4] and not a problem.

As described above, it was confirmed that the power transmission efficiency, temperature and vibration were as expected and not problematic.

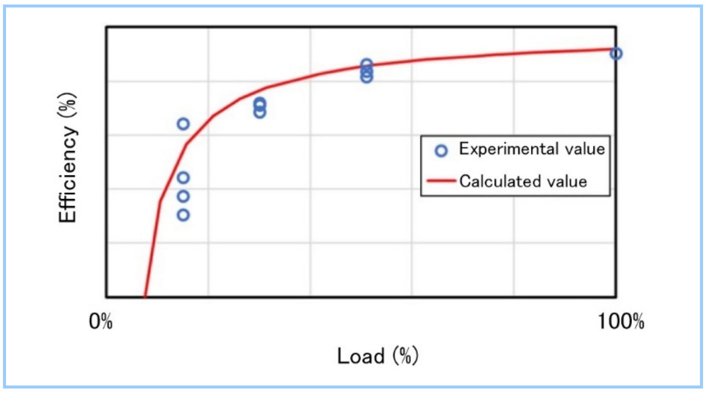

Figure 7 Measurement results of bilateral gear efficiency
It was confirmed that the experimental and calculated values of the efficiency almost agreed.

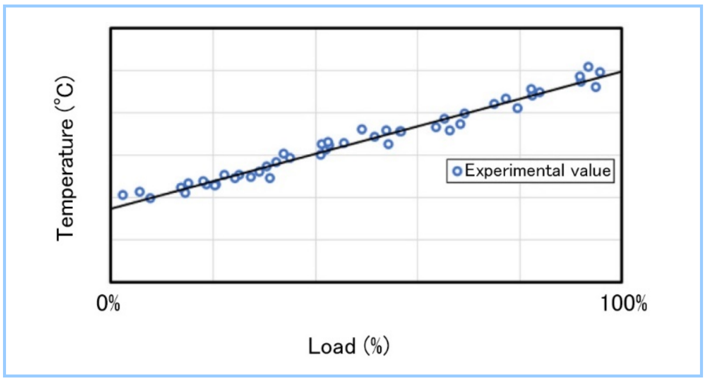

Figure 8 Measurement results of internal gear temperature
It was confirmed that the load and temperature were almost proportional to each other.

5. Conclusion

MHI designed and manufactured a 50 kW, 17,800 rpm prototype bilateral gear assuming its use in mobility applications and verified with a load test that its power transmission efficiency, temperature and vibration were as expected. As a result, it was shown that the bilateral gear is a speed reducing mechanism effective for greatly downsizing drive units and can be practically used even for mobility applications that require high output and high rotation speed, such as automobiles. In addition, since the structure of the bilateral gear is similar to that of planetary gear, no special expertise is required for assembly, unlike HarmonicDrive® units, so excellent manufacturability can be expected. In the future, we will promote the use of the bilateral gear for our transportation equipment products, which leads to the creation of new vehicle concepts.

References

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