Latest Technical Trends regarding Hub Unit Bearings

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Facing the increasingly pressing needs for compact, lightweight and high-performing automotive parts and the trend toward modularization, automotive wheel bearings have evolved into hub unit bearings. More recently, 3rd generation hub unit bearings have been in high-volume production.

In this paper, various problems concerning 3rd generation hub unit bearings and the technology used to resolve such problems are introduced.

***Key Words**: hub unit bearing, automotive wheel bearing, moment rigidity, FEM analysis, high-precision hub flange*

1. Introduction

In response to recently increasing needs for compact, lightweight and reliable components as well as the trend toward component modularization, automobile wheel bearings have been combined with other wheel components such as knuckles and hub shafts to form integrated wheel components referred to as hub unit bearings hereinafter.

Moreover, along with recent requirements for automobile suspension components to be more environmentally friendly and safer, automotive wheel bearings are being required to exhibit technological improvements including better performance and higher functionality.

The author previously presented a report[1)] on technical trends regarding hub unit bearings focusing on their design features. This report will introduce some recent product technology projects.

2. Technical Challenges related to Hub Unit Bearings

Hub unit bearings are classified as 1st, 2nd and 3rd generation in accordance with their mode of integration with other components. Each of these types has been already commercialized.

Figure 1 shows a typical 3rd generation hub unit bearing which lately been predominantly used for the driven wheels of passenger cars. The 3rd generation hub unit bearing is comprised of a 1st generation ball bearing unit, a flange integrated with the outer ring for mounting on the knuckle, and a hub shaft integrated with the outer side inner ring.

Hub unit bearings installed in passenger cars are mainly the ball bearing type. However, the pattern of evolution from 1st generation to 3rd generation for the driven wheel has not been the same as that for the driving wheel.

Table 1 shows the advantages and disadvantages of 1st generation and 3rd generation hub unit bearings from the standpoint of the vehicle.

Regarding the driven wheel, the advantages of 3rd generation type compared to 1st generation type are evident,

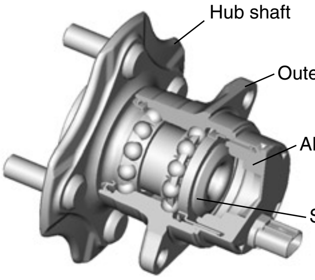
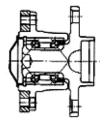
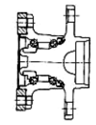
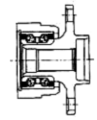
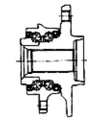


Fig. 1 3rd generation hub unit bearing

Table 1 Advantages and disadvantages of 3rd generation hub unit bearing

Items		Driven wheel		Driving wheel	
		1st gen.	3rd gen.	1st gen.	3rd gen.
Sketch					
Cost		△	○	△	△
Lightweightness		×	○	×	△
Performance	Life	△	○	△	○
	Stiffness	×	○	×	○
	Running torque	△	○	△	○
	Flange runout	△	○	△	○
Sensor acceptance		○	○	△	△
Compactness		×	○	×	△
Overall evaluation		×	○	×	△

Advantage: ○＞△＞×

and the 3rd generation type has already achieved predominant use. Regarding the driving wheel on the other hand, the 3rd generation type's advantages of compactness and lightweight are less obvious due to dimensional limitations at the connection between the driving axle and the hub unit bearing. That is why the evolution to the 3rd generation type has not been as rapid as that for the driven wheel.

However, in view of the advantages of integrated units in the installation process, it is expected that 3rd generation hub unit bearings also will be adopted more broadly for the driving wheels. Consequently, future technological development will most likely focus on 3rd generation hub unit bearings.

Figure 2 is a summary of various needs related to 3rd generation hub unit bearings and examples of corresponding technology being employed.

In this paper, these issues and the technology employed to resolve them are described.

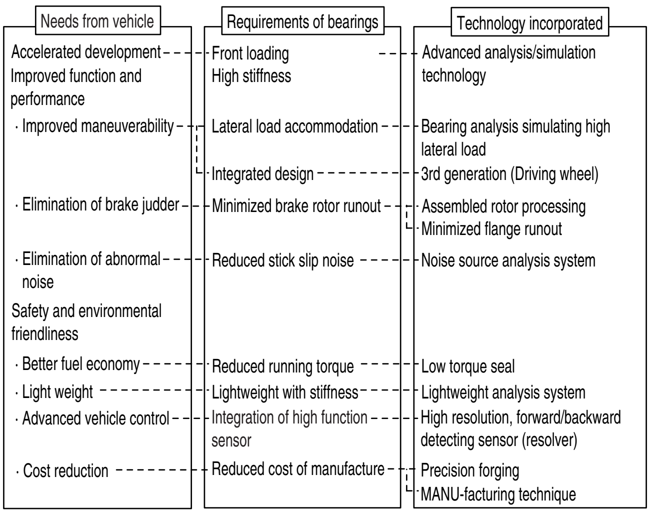


Fig. 2 Current vehicle needs and solutions promoted in hub unit bearings

3. Progress of Analysis and Simulation Technology (for Shortening Development Period)

Until this point, development evaluation of hub unit bearings has often relied on experiments. This approach, however, has caused delay in the development period because any problems revealed during prototype evaluation have necessitated repeating the development processes from design to prototype manufacture to evaluation testing.

However, recent advances in computers' processing capability and the progress of numerical analysis technology have made it possible to conduct desk investigations that used to be impossible.

In order to accelerate development as well as to reduce prototype cost, Koyo has promoted "front-loading" of the development process by use of CAE so that designers can assess their designs against final objectives themselves by using CAE.

Specifically regarding hub unit bearing analysis, Koyo uses noise and strength/stiffness analyses to reduce the number of experiments as well as stress mechanism analysis during and after processes such as shaft end clinching to obtain universal solutions.

As representative examples, efforts regarding strength/stiffness analysis and shaft end clinching analysis are introduced below:

3. 1 Strength/Stiffness Analysis

Although strength/deformation analysis has long been used as a basic type of FEM analysis, recently its reliability has been dramatically improved because of efforts to conform analysis results with experimental results.

Koyo has worked on refinement of FEM analysis for the strength/stiffness of hub unit bearings to improve consistency with experimental results and has established technology to keep analysis error within 10%[2).]

Figure 3 shows a comparison of FEM analysis and experimental results regarding hub unit stress. This shows that analysis results are highly consistent with experimental results under different load conditions.

Also, **Fig. 4** shows a comparison between FEM analysis of moment stiffness and experimental results. In this analysis, the stiffness of the knuckle (including outer ring) and hub shaft was analyzed by FEM, the bearing stiffness was calculated by a program developed in-house, and the moment stiffness of the entire unit was obtained by adding the values computed for each component. Here again, the analysis results had high consistency with the experimental results.

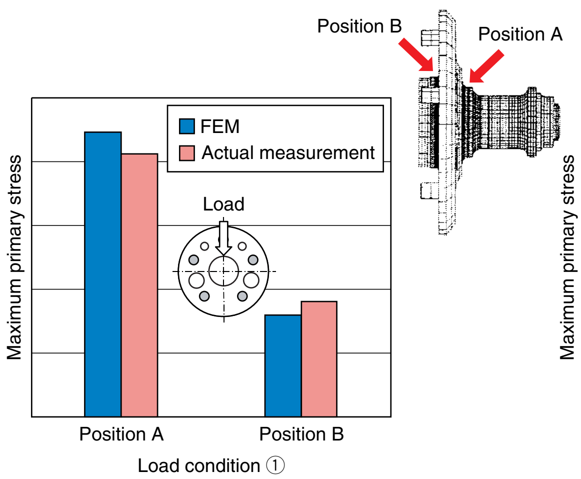


Fig. 3 Comparison between actual measurement results and analysis regarding stress

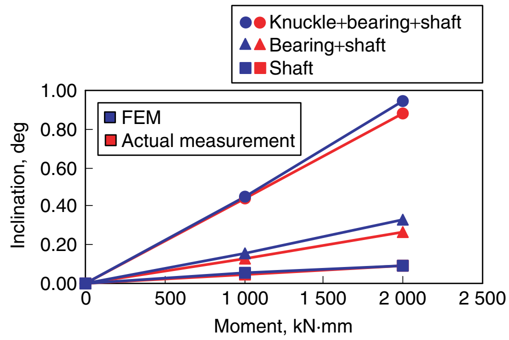


Fig. 4 Comparison between actual measurement results and analysis regarding moment rigidity

3. 2 Analysis of Shaft End Clinching Process

Shaft end clinching is a technique for forming the end of the hub shaft in which the inner side inner ring is mounted, by way of oscillation clinching, to locate the inner ring permanently as well as to provide the bearing with appropriate axial force.

This shaft end clinching not only eliminates control of bearing preload in the vehicle assembly process but also improves reliability in preventing the problem of inner ring looseness that cannot be solved by the conventional nut-tightening method. Recently, therefore, this shaft end clinching is increasingly being adopted.

On the other hand, because shaft end clinching involves the special plastic deformation process oscillation clinching, whose mechanism is hard to visualize experimentally, it is indispensable to employ analysis by CAE for mechanism evaluation.

Figure 5 shows a chronological representation of the simulation analysis of the shaft end clinching process[2). Thanks to advances in this analysis method, stress conditions during the process, which had been difficult to obtain, can now be obtained so that the optimum process design is possible.

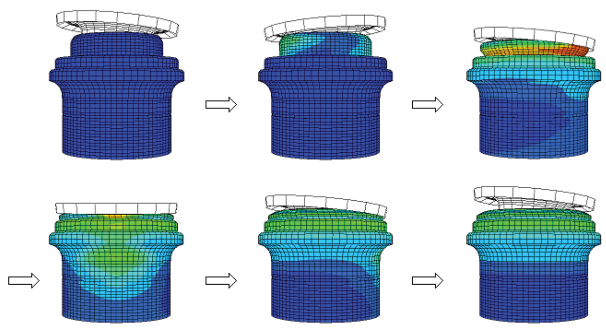


Fig. 5 Simulation of shaft clinching

4. Measures for Function and Performance Improvement

Along with the evolution of hub unit bearings from 1st generation to 3rd generation, bearing manufacturers have been required as unit manufacturers to participate in the resolution of problems from the standpoint of vehicle performance.

Some examples of contributions made by 3rd generation hub unit bearings to the improvement of vehicle function and performance are introduced below.

4. 1 Measures for High Stiffness and High Lateral Load

Recently, progress in vehicle movement control technology has been remarkable. Various types of system control technology such as anti-lock brake systems (ABS) are provided as standard equipment to improve the safety and comfort of vehicles.

On the other hand, such advances in vehicle control have tended to increase the load on components around the suspension. In particular, these days hub unit bearings are being required to have greater strength so that they can withstand increased lateral loads. In addition, hub unit bearings with high stiffness are being demanded for the improvement of maneuverability.

In design work, these requirements must be considered in conjunction with requirements for compactness and lightweightness using the analysis techniques discussed in section **3** above.

Koyo is working to improve bearing stiffness analysis specifically in regard to lateral load conditions in order to provide optimum bearing designs to vehicle manufacturers based on rigorous utilization of simulation analyses.

Figure 6 shows an example of analysis results regarding outer ring deformation under high lateral load. As discussed in above section **3.1**, the moment stiffness of a hub unit bearing can be evaluated as the sum of bearing stiffness and the stiffness due to elastic deflection of the components, implying that substantial deflection of the outer ring may cause a decrease of stiffness as a whole unit. In this particular case, the outer ring flange area is ingeniously designed to ensure adequate stiffness against high lateral loads.

Figure 7 is the stress analysis of the hub shaft to be combined with the outer ring shown in **Fig. 6**.

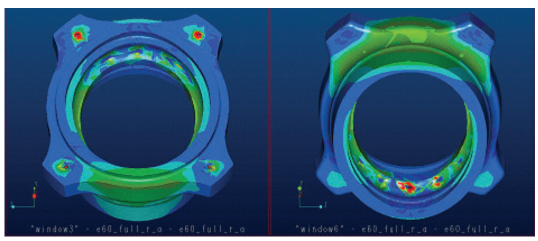


Fig. 6 FEM analysis for outer ring deformation

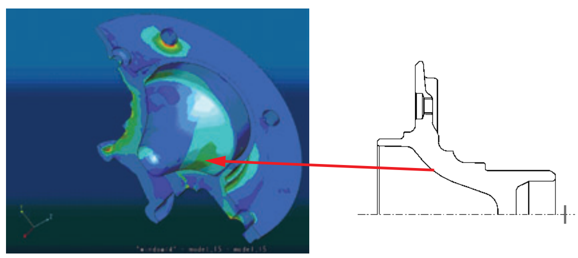


Fig. 7 FEM analysis of shaft stress

In order to design a bearing with high stiffness, it is generally effective to increase the pitch circle diameter of the balls. This approach, however, increases the size, and hence weight, of the bearing. Therefore, to counter this weight increase, it becomes necessary to make the hub shaft hollow, although the hollowed bore side can become the maximum stress occurrence position leading to shaft fracture under high load. In this case, therefore, the analysis method verified to have consistency as described in the section **3.1** was employed to determine the optimum hollow shaft design that would provide the required strength while keeping lightweightness. Bearings with this design are now in commercial production at Koyo.

4. 2 High Precision in Hub Flange Runout

In order to counter the brake judder and brake whining problems of vehicles, R&D has been carried out to establish technology to minimize hub flange runout with the aim of reducing brake disc rotor runout.

Figure 8 shows the development of rotor runout in the axle assembly.

Until this point, in order to improve runout precision in regard to hub unit bearings and rotors, we have endeavored to improve the design and processing methods of their individual components. Also, when individual component accuracy was not sufficient to satisfy the required accuracy of the assembled unit, attempts were made to secure higher accuracy of rotor runout of the axle assembly by implementing phase alignment at the time of assembling after measuring the flange runout and rotor runout of the hub shaft (Phase Ⅰ, Ⅱ).

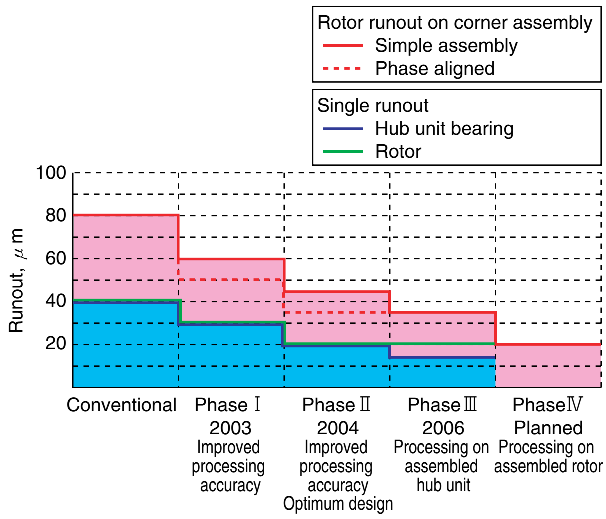


Fig. 8 Development of high-precision hub flange runout

While the contribution of rotor runout accuracy in preventing brake judder and brake whining noise is a focus of attention, a high level of accuracy that cannot be obtained by improvement of individual component alone is being demanded these days.

To satisfy such requirements, Koyo has recently developed a process technique to refine the flange accuracy after assembly. This enables accuracy that could not be attained by simply assembling individual components (Phase Ⅲ).

For further improvement of accuracy, it is also conceivable to machine the rotor surface after assembling the hub unit bearing and rotor into an axle unit (Phase Ⅳ). However, it has been adopted in only few cases as it is accompanied by a number of problems.

4. 3 Improvement of Noise Analysis Technology

The problem of noise from around the suspension used to be handled by automobile manufacturers. With the increased adoption of 3rd generation hub unit bearings, however, bearing manufacturers are also involved more and more in solving such problems.

The noise around the hub unit bearing is rarely generated in the bearing itself but rather at the junction with the rotor and the drive shaft.

Figure 9 is an example of fretting analysis by FEM performed to prevent the stick slip noise generated at the junction between the hub flange, the rotor and the wheel[3]. Fretting is a phenomenon of wear between two joining surfaces due to repeated minute relative sliding caused by the relative difference in stiffness between those two joining bodies. The wear particles influence the wear factor of the joining surfaces and cause the stick slip noise. Therefore, by analyzing the contact stress distribution in the area where two parts repeatedly contact and detach in operation and computing the workload of minute sliding, it becomes possible to include fretting prevention measures in the design stage. Since this contact stress analysis result matches the result of an experiment conducted in parallel, the contact stress analysis has proved to be an effective means of preventing fretting at the design stage.

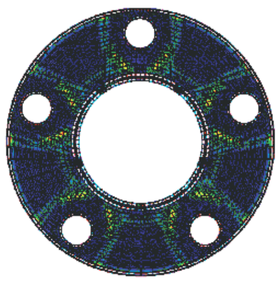


Fig. 9 FEM analysis result for fretting status

5. Safety and Environmental Friendliness Technology

These days the automotive industry is placing emphasis on technology for improvement of fuel efficiency and advanced vehicle control technology for better ride comfort and safety. Regarding suspension related components, efforts are being made to reduce bearing torque in order to improve fuel efficiency and to develop sensor integrated hub unit bearings for the advancement of vehicle control.

These advanced technologies are presented below.

5. 1 Development of Low Torque Seal

Recently, reduction of CO_2 based on the Kyoto Protocol and improvement of automotive fuel efficiency are focuses of attention as socially and ethically significant subjects in consideration of the future exhaustion of energy resources.

In response to the needs for fuel reduction in automobiles, Koyo has been working on the reduction of torque in hub unit bearings. At this moment, Koyo has been successful in developing and commercializing a low torque hub unit seal that has a substantial effect on bearing torque reduction.

Table 2 shows seal designs of commonly used hub unit bearings and the contribution of each seal lip to total seal torque. Through decreasing torque by reducing the lip interference of the main and auxiliary radial lips, which account for a significant part of seal torque, while in order to prevent resultant deterioration of sealing effectiveness against muddy water improving the sealing effect of the axial lips, which do not cause as much torque, we developed a low-torque seal that can be used in the market.

Table 2 Seal design of hub unit bearing and contribution of each lip to seal torque

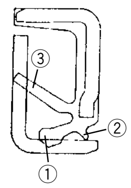
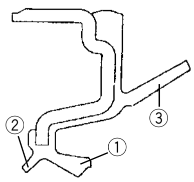
	Pack seal	Shaft seal
Seal design		
①Radial main lip	40~50%	
②Radial side lip	30~40%	
③Axial lip	10~30%	

Figure 10 shows the results of rotational torque tests on the conventional and developed seals. The developed design for both the pack seal and the shaft seal showed 40% reduction of torque. Also, in a muddy water test, the low torque seal showed durability equivalent to that of the conventional seal.

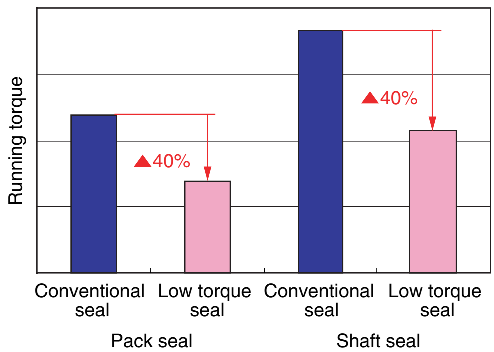


Fig. 10 Torque measurement result

With the development of this low torque seal, the hub unit bearing could achieve 20% reduction in torque compared with the conventional type.

5. 2 Lightweight Optimization Analysis

Reduction of unsprung weight has a remarkable effect on improved maneuverability and reduced fuel consumption. A compact, lightweight hub unit bearing does not only realize these benefits but also allows flexibility for design of surrounding components. Therefore, size reduction has been a highly prioritized design objective for 3rd generation hub unit bearings.

However, excessive reduction of weight may cause a loss of stiffness, which leads not only to poor steering feeling but also to component fracturing, the worst mode of failure for a suspension component.

Therefore, Koyo has working to achieve a lightweight design for 3rd generation hub unit bearings, carefully utilizing the strength/stiffness analysis technology discussed in the section **3.1** above.

Figure 11 shows an example of stiffness analysis of a weight-reduction design wherein a 30% and over reduction of weight compared to its conventional counterpart has been achieved while maintaining strength and stiffness. It represents a successful evolution from the old approach, which depended mainly on the designer's guesswork, to a new lightweight design approach through the established analysis methods.

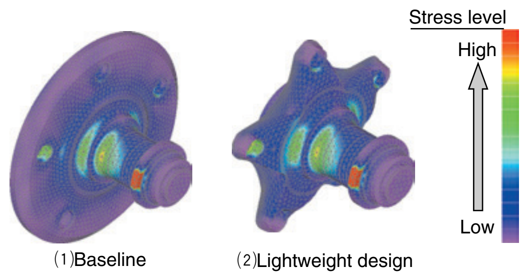


Fig. 11 Example of lightweight hub shaft

5. 3 Integration of High-Resolution and Forward-Backward Detection Sensor

Recently an increasing number of hub unit bearings are required to have an integrated ABS sensor. Also, with the advance of vehicle control systems, vehicles that utilize output signals from the ABS sensor for other vehicle control purposes are also increasing. Therefore, it will be necessary in the near future to develop new technology that provides the sensor integrated in the hub unit bearing with intelligent functions (high resolving power, forward-backward detection, absolute angle detection, etc.) over and above the ABS sensor function. Consequently, Koyo has launched a new development project to integrate a VR type resolver in the hub unit bearing as a next-generation high-function sensor.

Figure 12 shows the structure of the developed product. The sensor is composed of a stator and a rotor. As the rotor is made of iron core, it can be integrated with the bearing inner ring.

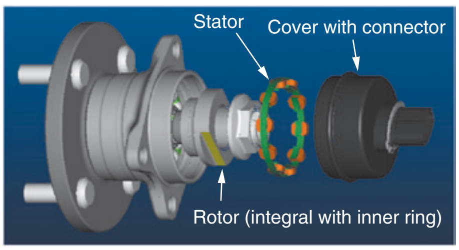


Fig. 12 Structure of hub unit bearing with built-in resolver

Since the resolver has resolving power overwhelmingly higher than that of the conventional ABS sensor, it can be used very effectively for low-speed control mainly for position control, etc. to prevent the vehicle from reversing during uphill climbing.

Figure 13 shows a comparison of position control responses due to the difference in resolution between the ABS sensor and the resolver. Even in the low-speed region, where the ABS sensor may have transient response due to inadequate resolving power, the resolver's high resolution enables accurate control.

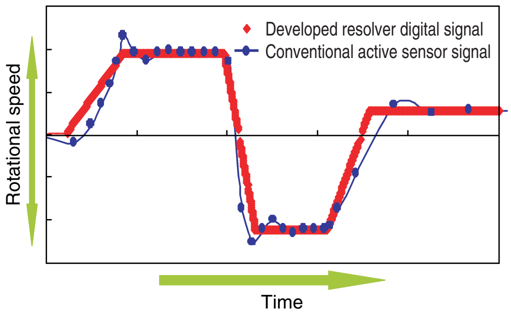


Fig. 13 Resolution comparison between ABS sensor and resolver

6. Cost Reduction Technology

Recently cost reductions are increasingly being demanded for automotive components, and there are strong requests to develop new technology that can drastically change current manufacturing processes.

Hub unit bearings have not been an exception. The followings are some examples of cost reduction technology that we have been working on:

6. 1 Precision Forging

The progress of forging technology, especially the recent advance of forging die technology, has made available the high-precision forging technique called "near net forging." **Figure 14** shows an example of reduced machining allowance achieved by near net forging. Since the production cost of a hub unit bearing depends substantially on upstream processes such as forging and machining, this high-precision forging is a very effective means of cost reduction.

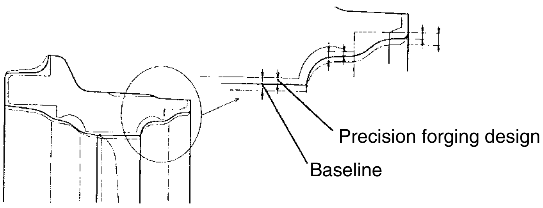


Fig. 14 Precision forging

6. 2 Production Innovation

Koyo has been striving to achieve companywide production innovation named "PPI"[4]. The key phrases for this campaign are "change the process," "change the facility," and "change the product," and the concept is that of "getting back to square one and building production process technology anew."

Based on this concept, a renovation of processes that have been taken for granted is in progress now. The following are examples of such renovation in the bearing production line.

① Elimination of selective fitting (assembly of bearing races and balls based on individual measurement of raceway dimensions to control bearing internal clearance)

② Change of three-dimensional conveyance systems linking production equipment to two-dimensional systems (flat systems)

This campaign is beginning to bear fruit in cost reductions as a result of innovative manufacturing methods, space saving, and improved operating efficiency that has been achieved. On top of that, the fresh innovation awareness engendered in the minds of employees through this all-out campaign is expected to be a future source of cost revolution.

7. Conclusion

This report presented the latest technological trends regarding hub unit bearings, which have been increasingly adopted for automobile wheels as a result of rapidly changing circumstances such as advances in vehicle control technology and demands for improved fuel efficiency.

We wish to continue development efforts in the hope that we can stay ahead of the needs of automotive manufacturers and renovate ourselves into an automotive component supplier that can propose lucrative technology to customers.

References

1) T. Numata: Koyo Engineering Journal, 162E (2002) 32.
2) K. Kajihara: Koyo Engineering Journal, 167E (2005) 35.
3) K. Yamakawa and K. Kajihara: Koyo Engineering Journal, 165E (2004) 41.
4) M. Isaka: Koyo Engineering Journal, 167E (2005) 10.

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