Product realization history of 8 products development mainly for railroad and automobile use

鉄道と自動車の重要部品に関する 8つの製品開発の実現とその過程

Haruo Sakamoto*
坂 本 東 男

要 約

本論文は主として鉄道や自動車の重要部品に関しての開発と実用化の歴史を記述している。目的は製品の開発と実用化に要求される事項を明らかにする事である。製品は著者が過去 40 年に出会ったものである。著者は住友金属工業（株）―現新日鉄・住金―で 1970.4−1995.8 の間技術者であり、その後 1997.4−2009.3 の間高知工科大学の教授で現在は名誉教授である。また 1999.1−2008.1 の間エコロギー四万十の代表取締役でその後相談役となっている。 社会的に需要な鉄道と自動車他に関して 8 つの製品を主に住友金属で開発し実用化してきた。製品は設計に関連している。以下が歴史である。

ABSTRACT

This paper describes a history of development and realization for important products mainly for railroad and automobile. The purpose is to try to clarify what is needed for products development and realization. The products are those the author had encountered in the past 40 years. The author had been an engineer in Sumitomo Metal Industries Co. in Japan (Nippon Steel & Sumitomo Metal Co. at present) during 1970.4-1995.8, and a professor of Kochi University of Technology during 1997.4-2009.3. Now he is a Professor Emeritus of the university. He also used to be a president of Ecology Shimanto Co. during 1999.1-2008.1 before changed as a consultant of the company. 8 products of mostly socially important products for railroad and automobile were developed and were put into realization mainly in Sumitomo Metal Industries Co. The products relate to design work. The following is the history.

Keywords: Shinkansen, induction hardened axle, curved plate wheel, forged brake disc, eddy current brake unit

* 高知工科大学・名誉教授、昭和 20 年（1945）6 月 30 日生まれ、阪大理物理修士終了・Stanford 大工機械修士終了、住友金属工業（株）・高知工科大学・（株）エコロギー四万十、機械学会賞 7 件（米国機械学会論文賞、日本機械学会技術功績賞、他）・その他賞 7 件（四万十町大正特別功労賞、科学技術長官賞注目発明、他）

1 Introduction;

The author had been engaged in products development and realization in Sumitomo Metal Industry Co. for 25 years since 1970. He moved to a university in 1997, Kochi University of Technology, and worked as a professor for 12 years. Since moving to the university, the budget of research and development was small compared to the one of the company. Due to such a circumstance, the relatively big work was hard, and, however, he had contributed to papers. The start of products development and realization was the development, design, and manufacturing of important products for railroad such as axles and wheels.

At the end of this paper, the author tries to summarize the important factors for development and realization he feels from his past experience. For details in each explanation, literatures at the end of the paper can be referred.

2 Realized products;

2.1 Induction hardening of Shinkansen (Japanese bullet train) vehicle axle (1971)

One year later after joining to the company and finishing the training period, the development theme was induction hardening of Shinkansen vehicle axle. The mission was changing induction hardening cycle from 10 Hz to 3 Hz in order to deepen the hardened layer. Deeper layer gives larger safety. However, the technology was not so easy, and needed to take night shifts during the period of having a born child. Since the technology is pretty hard, the technology is called as oriental magic in Europe. It was October, 1971, when the aimed hardening was successful, and mass production started. Since then, the induction hardening production has continued without any trouble, and 41 years have passed. Figure 1 shows the axle[1] and how installed in a bogie truck[2] . The dark area in the axle is the hardened one, and the depth is 2.5 mm in the straight part and 4.0 mm in the anti-gear side part. The induction hardening produces large compressive stresses in the hardened layer, and it is considered that such compressive stresses let cracks delay to propagate. However, this is just an assumption with no scientific evidence. Axles rotate 10^8-10^9 cycles, and the most cycle is about $2x10^9$ (a vehicle runs $7x10^6$ km). In the past, conventional fatigue tests had been done up to 10^7 cycles which is much smaller than such axle' actual rotation, and were judged whether or not safe.

Although large compressive stresses are considered to be effective for cracks not to propagate, the experimental verification has not been conducted so far. The reason is that such an experiment needs time. For example, a 10^8 cycle fatigue test needs about 3.2 years, if the test speed is 1 Hz. If 10 Hz, it needs 3.8 months. Therefore, the fatigue experiment was planned with a vivro-fore machine that makes fatigue testing with 70 Hz. As a result of the experimental and analytical studies, it was found that cracks do not propagate under the condition of normal running usage[3] . Even though some fretting cracks originate, cracks do not propagated due to large compressive stresses. The author as an engineer in charge contributed to the technology establishment and to papers.

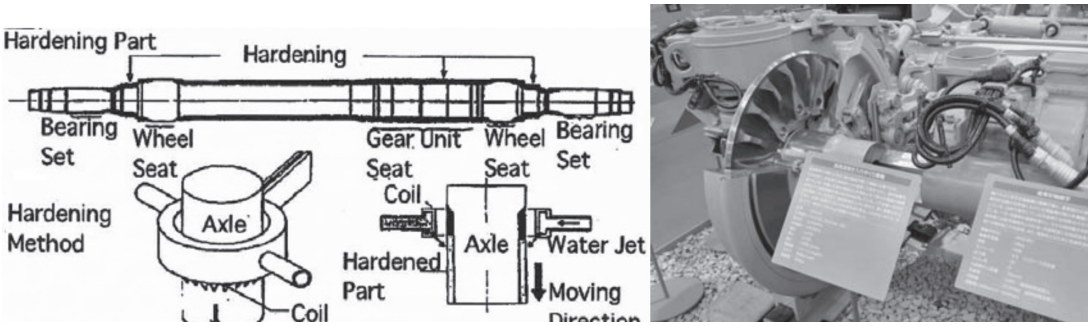

Figure 1 Shinkansen axle[1] and assembly in a bogie truck[2]

2.2 New profile wheels for US railroad(1978-1981)

In the early 1970 years in the US, a lot of derailment had occurred due to wheel fracture. In 1985, about 100 derailments happened only because of wheel fracture. It is hard to imagine such a situation compared to Japan, where derailment or even wheel fracture is rare. In 1978-81, a team project in Sumitomo Metal Ind. Co. to develop wheels against fracture had been conducted, and the author was a main member. It was clarified that the cause of wheel fracture was the tensile residual stress, and it was caused when cooled down after heating by an excessive braking. Brake excessive heating can be caused by a condition of long drag braking, or of overhanging shoe, and with two conditions together. Thus, the research for obtaining wheel configuration of low residual stress origination was performed. The obtained configuration is the one of large lateral offset plate between at rim center and at hub center. This was confirmed both by empirical and analytical studies. Wheels with such an idea[4),5),6)] are now exported to various US railroads, and contribute to the safety. The author contributed to idea, experiment, analysis, papers, patents, and final product realization.

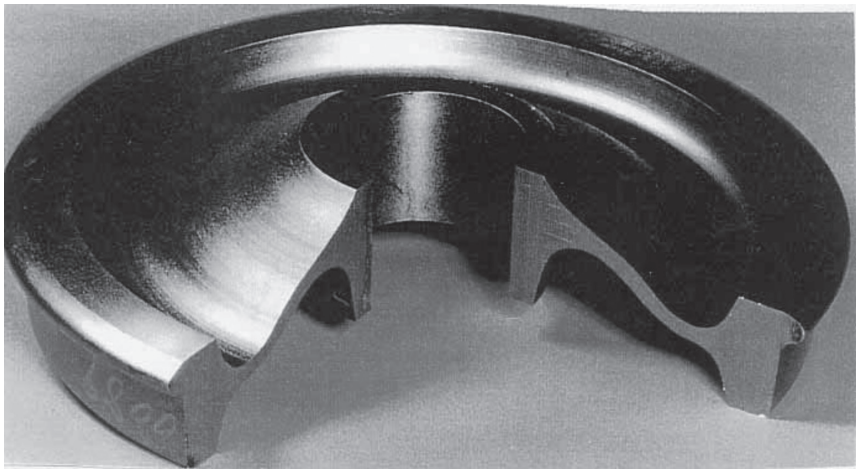

Figure 2 New profile wheel for US railroads[3]

2.3 Forged brake disc with fins for high speed Shinkansen vehicles (1978-1884)

Basic brake system for Shinkansen vehicles is electric. When electric brake fails, mechanical brake works. Higher speed Shinkansen vehicles require higher brake energy absorption. Compare to the past 210 km/h, a braking from 300 km/h needs double energy absorption. Original brake discs when inaugurated had been cast iron discs, and can not hold out against such higher energy. Therefore, forged steel discs were studied in a manner that the discs are equipped with conventional wheels. Since the conventional brake discs have fins at the back side, a 9,000 ton hydraulic press, and afterwards rotary dishing press, was used to make fins by forging. Conventional fins were made by casting and the shape was thin. By forging, thin fins are hard to be produced. The fin configuration had been studied, and found to show enough cooling effect even with the gentle slope like Mt. Fuji. From Nozomi, the Shinkansen vehicles started to apply the forged discs with fins. Figure 3 shows the disc and the assembly. The author contributed to idea, experiment, analysis, papers, and patents. The final realization was accomplished by successive engineers.

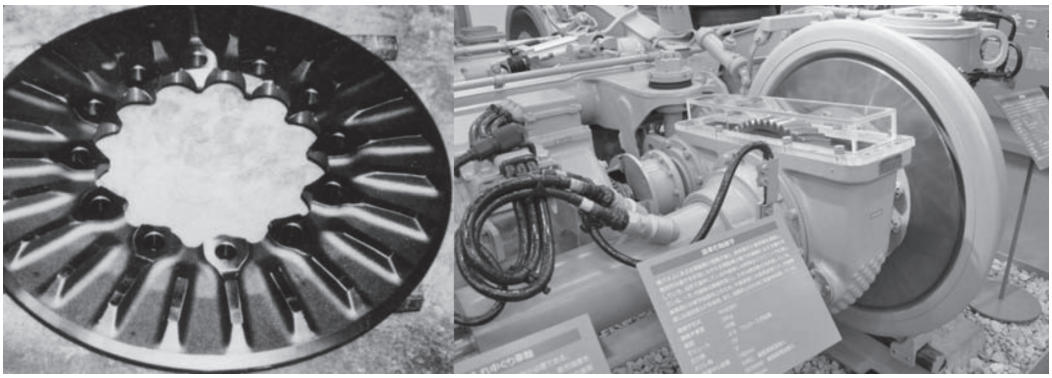

Figure 3 Brake disc for Shinkansen vehicle (back side)[8] and its assembly[2]

2.4 Eddy current brake disc for two-story Shinkansen vehicles (1984-1985)

Shinkansen vehicles are mostly all-motored. For more luxury vehicles, two-story vehicles without motors were planned in around 1984. Among 16 cars, 4 cars are to be trailed (without motors), and special brake equipments were required instead of conventional brakes. The eddy-current brake system was studied. However, because of repeated brake application from a high speed, the disc may have suffered to high temperature rise due to sliding action between discs and linings. Such an application may cause crack initiation and propagation on the disc surface. To avoid fracture from cracks, the material was required to have high fracture toughness. A variety of material candidates were experimentally studied. Finally, the material of modified (grain refined) AISI 4330 steel was selected. The brake discs were put into service since 1985. Figure 4 shows the ECB discs. After 1/4 decades passed, the vehicles were change to new series, and two-story Shinkansen vehicles for Central Japan Railway disappeared. Two-story Shinkansen vehicles remain in Tohoku Shinkansen vehicles of JR East. The author contributed to the material selection.

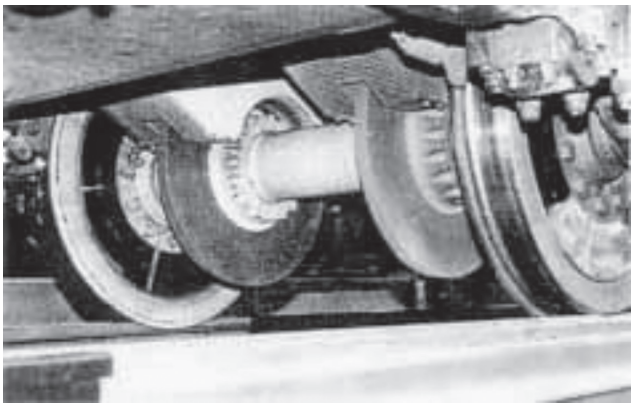

Figure 4 Eddy-current-brake system for two-story Shinkansen vehicles

2.5 New corrugated wheels for domestic use(1990)

This is an application of 2.2, new profile wheels, to the domestic use of corrugated wheels. As is for US wheels, the plate part has large lateral offset between at rim center and at hub center. The author contributed to idea and design. Figure 5 is the new corrugated wheel.

Figure 5 New corrugated wheel for domestic use[2)]

2.6 Permanent magnet eddy current brake system for truck & bus use (1990-1992)

As auxiliary brake units for truck & bus use, those by electric magnets or fluid have been used in Europe and USA. Such units have some issues to be improved. These are to be heavy, to need to modify chassis for heavy loading, and to have batteries. Because of such reasons, auxiliary brakes were not popular in Japan. We applied the rare earth permanent magnets of

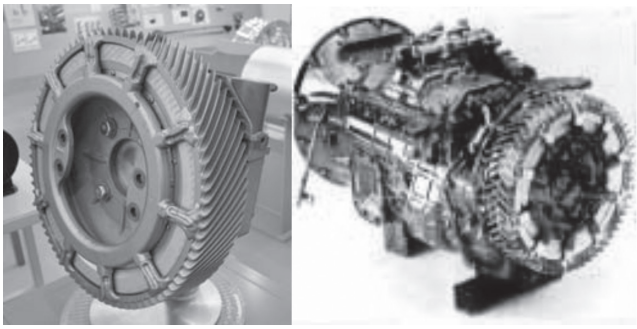

Figure 6 Permanent magent type eddy current brake unit(ECB retarder[2),9)])

Nd-Fe-B, which was developed and patented by Sumitomo Special Metals Co. (Neomax at present). Trial production, performance test, and endurance test had been repeated. Joint work to develop with Isuzu motors had been performed, and the product was put into commercial use[2),9)] from around in 1992. Figure 6 shows the unit and assembly. The author contributed to joint development, commercialization, and papers.

2.7 C/C brake unit, brake control unit, and truck for linearly levitated trains inYamanashi Experimental line (1991-1995)

In 1990, JR Central started to develop linearly levitated trains. The trains should have new concept for each component for running at a very high speed at around 500 km/h as a revenue service. Primary concern is light weight, and main components to be developed were C/C (carbon reinforced carbon) brake units, brake control units, and trucks. Sumitomo Metal Industries Co. jointed to develop as a partner with JR Central. They were designed and developed, and were delivered to Yamanashi Experimental line in 1997. As for brake units, the braking from the world fastest 550 km/h succeeded. Figure 7 shows the C/C brake unit. The author contributed to the proposal of cooperated joint development with JR Central and to development of C/C brake unit, brake control unit, and truck. He also contributed to papers and patents. As the first series of Yamanashi Experimental line, the products were delivered through JR Central.

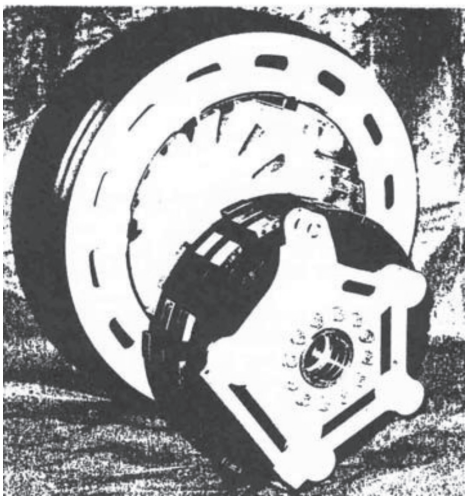

Figure 7 C/C brake unit for the first series Yamanashi trains[10)]

2.8 Hybrid street light with wind power and solar cell (1998-2000)

When an earthquake occurs, big tsunami may happen like in March, 2011. When tsunami occurs, people needs to firstly escape. At night, no light can be given, since electric cables may shut down. In order to obtain self-powered street lights, wind power and solar cell were applied. Figure 8 shows the self-powered street lights. At present, about 70 units had been installed in mainly Kochi prefecture. 20 kW generators also had been developed, and are expected to be applied at a gymnasium where people escape together and stay. The author contributed to idea, design, papers, and patents. A company in Kochi paid a roll of production.

Figure 8 Wind and solar hybrid self-powered street light[11)]

3 Products development not reached to realization

So far the products realized were explained. Products that were developed can not always be realized, since they are hardly realized. A small part of the development can be put into commercial use. The followings are those who are not realized, but were reported in papers or technical reports.

These are tilting vehicle controlled by air spring[12)], truck for shipbuilding[13)], noise-proof truck[14)], tension leg for marine structure[15)], aluminum and titanium forged product[16)], aluminum coating for protecting lightning failure of wind power generator[17)].

Those that have not reported by papers or reports are not few. Figure 9 shows the trial production of a new truck frame by GFRPs (Glass Fiber Reinforced Plastics) and aluminum joints. The frame was unfortunately not realized.

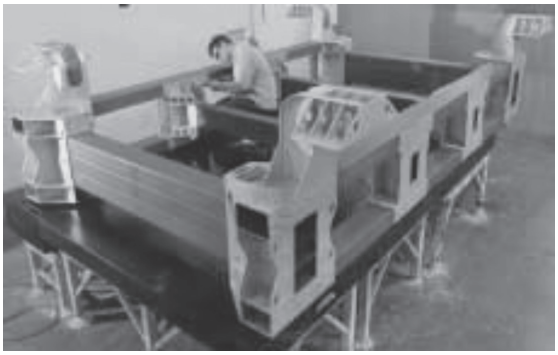

Figure 9 Trial production of a truck frame by GFRPs and aluminum joints

4 Concluding remarks

The author had been in charge of products development and realization for more than 40 years. From the author' experience and his dogmatic idea, important issues for products development and realization are summarized.

(1) Firstly, an idea should come first for development, and the target to develop should be clear.

(2) Secondly, should act toughly with own' idea, understanding the state of the art.

(3) Thirdly, knowledge and technology from not only by own self but also outside from both of domestic and abroad should be considered.

(1) is the basic and fits to all cases of 2.1-2.8. In case of 2.1, induction hardening of Shinkansen (Japanese bullet train) vehicle axle, toughness for development was most important. In case of 2.2, new profile wheel for US railroads, (2) and (3) related. In the development, a university's adviser suggested to use the conventional theory of Elasticity to qualitatively understand effective factors. The adviser, Professor Emeritus R. C. Steele of Stanford, is in the stream of A.P. Timoshenko, notorious Professor. In case of 2.3, forged brake disc with fins for high speed Shinkansen vehicles, not only (2) was important, but the knowledge of Fluid Dynamics was needed. In case of 2.4, eddy current brake disc for two-story Shinkansen vehicles, the knowledge of material was requested. 2.5 case of new corrugated wheel for domestic use is an application of 2.2. In case of 2.6, permanent magnet eddy current brake system for truck & bus use, knowledge of inside and of the cooperated company was utilized. Inside the company, an engineer who is good at Mathematics formulated from Magnetism, and showed the guidance to develop. In case of 2.7, C/C brake unit, brake control unit, and truck for linearly levitated train in Yamanashi Experimental line, inside and outside knowledge was applied. Especially, the technology of carbon-carbon composite brake material can not be obtained in Japan. The technology has been developed and used in the US and Europe. The top maker, US BFGoodrich, was our partner for the products development. In case of 2.8, hybrid self-powered street light with wind power and solar cell, (1) was an example of idea. Instead of using electric magnets, core-less coil was used so that cogging torque can be minimized.

Finally, the author wishes successive engineers to take care of the state-of-the-art knowledge and technology in order not to take away human's life. State-of-the-art is not present technology but up-to-date or newest one. Please remind the tragedy of Germany Express

railroad derailment[18),19),20)] on June 3 in 1998, which was caused by a wheel' tire fracture. The fracture was from a crack that was originated from the tire inside face. Even thought German railroad had recognized that the concerned portion had needed to watch from the viewpoint of the strength, they had not surprisingly inspected the potion[19)]. If they inspected the portion, just like Japanese Shinkansen conducts the magnetic particle inspection on axles, the fracture may not occur. Perfect technologies do not exist, and things may break. This is the reason why we need inspection for such influential product as effecting human life. The concept of fatigue limit is the one we need to consider, since there is no scientific ground that fatigue limit exists as Professor Suresh S. of MIT mentioned[21)]. Fatigue damage tolerance design with proper non-fracture or fracture possibility is desirable.

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