RAILWAY TECHNOLOGY GEARED UP FOR THE 21ST CENTURY

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1. INTRODUCTION

In April 1987 the JNR which had long been the core of railways in Japan was privatized and split into several independent units, which are now leading the pioneering efforts carving out the future of Japan under a new regimen. The JNR created the Shinkansen system and in the course of improving it, it stood at the forefront of the railway technology in the world. The technical staff responsible for the successful development of the Shinkansen has been absorbed into the present Railway Technical Research Institute reorganized as a research foundation and is engaged continuously in the activities contributing to the progress of railway technology.

This paper discusses about what the railway technolgy should be like in the face of new realities unfolding with the 21st century not so far away and how the Railway Technical Research Institute should be prepared to confront the problems looming on the horizon.

2. FUNCTIONAL UPGRADING OF RAILWAY

In the industrializing society of the past, the railway was a "high technology" driving the economy and it has reached the limit of self-proliferation as a monopolistic mode of land transport. In the post-industrial society as we live in now, however, it is nothing but one means of transport competing against many others and its social utility depends on whether it can continue to be profitable or not. The immediate target of the railway research and development efforts is therefore firstly how to functionally upgrade the railway services, thereby retaining the patronage of the customers against the competitors and securing the necessary revenue.

2.1 Cutback of train time

Cutback of train time should be the target for any means of transport. Inauguration of the Shinkansen has marked the opening of a new high-speed era of the world railway.

In March 1985 when the Tohoku Shinkansen line began to operate from Ueno, the maximum train speed jumped to a new record of 240 km/h from 210 km/h at which the line had operated since the inauguration of the Shinkansen. Stagnation of the speed at that level as long as 20 years was attributable to the environmental problems involving the running noise of trains, but the problems have been solved in accord with the administrative environmental instructions (80 dB(A) at inauguration of the line, 75 dB(A) in three years at peak level in each). Meanwhile, final negotiations are in progress to realize in the near future 270 km/h on the Tohoku, Jo-etsu and San-yo Shinkansen lines and 230 km/h on the Tokaido Shinkansen line.

Research and development aimed at the maximum speed 300 km/h on the

Shinkansen lines are also underway since 1981. In this work the major themes are weight reduction of vehicles (both sprung and unsprung masses); levelup of current-collection system; control of track irregularities (both long wavelength and short one), but the most crucial theme would be the noise. The efforts for problem-solving should be focussed on the aerodynamic noise which augments in proportion to the 6th power of the speed, in addition to the other ones so far coped with, such as the rolling noise, the current-collection noise and the noise originating from the track structure.

For the privatized railway, an increased train speed on the existing Shinkansen lines would prove effective for an increased revenue, vis-a-vis the airlines in particular, but this presupposes low costs for modification of signalling and abatement of aerodynamic noise (microwave pressure) in tunnels.

The railways in Japan are predominantly narrow-gauge and full of curves for topographical reasons. Meanwhile, emergence of expressways running parallel to the railway lines produces urgency of railway speedup. We estimate the maximum allowable train speed on the existing narrow-gauge lines at 160 km/h on sections with no crossings and at 130 km/h (on account of restrictions on the emergency brake distance $\leq$ 600 m) on sections with crossings. Effective to cut back the train time will be the technology which contributes to increasing the average speed of trains, such as raising the curve-passing speed or setting higher acceleration/deceleration. For the purpose of raising the speed at curves, a pendulum car has been introduced for the electric train and a prototype car was lately completed in a challenge for the pendulum version of diesel car and it has been operated in a commercial service since March this year. For the purpose of increasing the acceleration/deceleration, an inspection car capable of continuously measuring the adhesion coefficient which vitally affects the vehicle performance has been developed contributing to a study to throw light on what we have long been "in the dark" about.

Even on narrow-gauge lines, a 200 km/h run would be feasible provided the line is a newly contructed one and its profile is suitable for speedup. At the beginning of this year a plan to lay a new high-speed narrow-gauge line between Kumamoto and Kagoshima (to run at about 202 km) and thereby cut back the necessary train time by about 50 % has been authorized by the Government.

2.2 Enhancement of convenience

The other alternative favored by the customers is an increased convenience and a ride comfort of the transport means.

2.2.1 Shortened transfer time

This will be tantamount to minimization of layover and cutback of total train time.

A plan is being contemplated to carry passengers from Fukushima on the Tohoku Shinkansen (standard gauge) to Yamagata, with the train moving into the narrow-guage line, which is to be switched to the standard gauge (the track to be partially tripled). Important problems involved would be how fast and safely to operate on the Shinkansen a short-length body vehicle matching the narrow-gauge and how to design a specialized turnout.

In an effort to realize a transfer-free through run of trains over electrified main line and non-electrified branch line, we have completed a coordinated operation system under which electric railcars are coupled to diesel cars on the electrified sections and they can be totally controlled via the computer; the system is already placed in commercial service of a tourist train.

2.2.2 Setting of trains meeting customer demand

Nothing would be more wasteful than to set a train carrying the "air" with no passenger or freight load. In contrast an overcrowded train would be a shame to the railway as a service industry.

A computer system which can set appropriate trains, anticipating the seasonal fluctuations of passengers or estimating from the status of initial seat reservations has been developed; its errors in speculation turned out less than 10 %.

Required train setting means selecting the optimum number of trains and the optimum makeup of a train. While the research for automatic coupling and uncoupling of cars into an optimum train makeup is going on, we have set to work on developing a "soft" coupling system under which two groups of motive units uncoupled can be run adjacent to each other with the distance controlled by ME between them, the basic conception here being that it is the connection of cars that makes it necessary to couple and uncouple them.

For the urban commuter transport, as many trains as possible must be squeezed into the limited time zones. Under the block system of train operation relying on wayside signals, there is a limit to the number of trains that can be set. Therefore we are studying a movable block system under which the train runs controlling the intervals between trains without relying on the wayside signals.

2.2.3 Relief of customers from seat reservation bother

In the motorized age the customers are likely to turn away from the conventional system of seat reservation which requires the customers themselves to go to the station.

With the advent of a compact seat reservation terminal set utilizing the common telephone channel, the seats can be obtained at hotels or from a salesman calling on the customer. Meanwhile we have already a prototype of the non-contact IC card which registers the trip route when the traveller holding the card flashes it at the ticket gate as he gets on or off a train at the station, the fares being automatically settled by bank transfer every month. Such a card will make it possible to check the high-frequency rail users and improve the service to be offered them, and this will lead to the possibility of introducing a cashless system applicable to other purposes than rail transport.

2.2.4 Station facilities adapted to customer flow

Tardy flow within a station is the first thing which offends the customers and this is liable to cause an increase in the transfer time. We are now engaged in development of an analytical system which enables a simulation of customer flow within a station by representing the customers as a unit mass and assigning a behavioral rule to it. Such a system will contribute to optimization of the location of the ticket window (or ticket vending machine); optimization of the site and width of the ticket inspection gate; and to determination of the effectiveness of notices, guides or announcements; further it may be evolved into a system for analyzing the movement of people in time of panic.

2.3 Improvement of passenger comfort

In those days when the railway monopolized the land transport, the term "passenger comfort" had rather a negative connotation that the passengers are not made unpleasant. In this age of competition, on the contrary, a positive comfort should be given them. "Convenience" mentioned earlier may be called a sort of comfort.

2.3.1 Vibrations and shocks

In order to abate the impact caused by track irregularities on the riding comfort of passengers, the track irregularities should be controlled for each wavelength, corresponding to the train speed. Shocks due to wheel flats or rail joints are another factor affecting the riding comfort and a special attention should be paid to the technique of braking force control and of the rail welding. A countermeasure for excessive centrifugal force caused by cant deficiency in curve is the pendulum car mentioned in the above, and active control in passing the transition curve is also highly effective. Meanwhile we feel the necessity of reviewing the profile of transition curve to fit it to the vehicle characteristic. In future, we think, the active control technique ought to evolve into an automatic control technique of trains which can cope with external disturbances such as vibrations, shocks.

2.3.2 Noise and air pressure variations in the train

Reduction of internal vehicle noise involves an element of technical development which conflicts with weight reduction of vehicle. On the other hand, it is imperative to hold down the air pressure variations in the train vehicle to a certain level when the train passes at high speed through a tunnel. Anyway, establishment of airtightness of train vehicle structure in coordination with ventilation performance is a technical matter of vital importance.

Decreased vibration and quietness in the Tohoku and Jo-etsu Shinkansen trains are now a topic among the travellers. The days may come when "quiet" is a unique merit the railway can boast of against airlines and auto transport.

2.3.3 Information

We already live in the age when the closed space of a train in which the passengers sit isolated from the outside information with no access to radio has an impact on their life. In the 21st century, the offering of necessary on-board information service to the passengers by telephone, fax, television set etc. through satellite communication, digital communication by LCX and internal network of optical fiber will be the standard image of the railway. We are energetically pursuing research and development in this direction.

2.3.4 Human engineering approach

Our approach to the passenger comfort has so far leaned to the hardware. Genuine pleasure of rail travel, however, should be a comprehensive one appealing to the five senses of humans. From this standpoint we have set to work on a research aiming at design and arrangement of comfortable interior space through analysis of the impacts of seating plan, color scheme, background music and services offered on the physiology and psychology of the passengers.

3. CUTDOWN OF RAILWAY COSTS

The second target in the research and development efforts of the railway amid stiff competition is cutdown of costs in order to hold the fares lower than a certain level. The practical railway management stands on the huge capital built up in the past. Usually a capital improvement costs dearly and often it needs a technical breakthrough to achieve an effective cost cutting.

3.1 Retrenchment of personnel expense

Personnel expense for railway operation and necessary maintenance of facilities must be pared down.

3.1.1 Maintenance-free installations

We have developed a maintenance-free track structure like the slab track devoid of the ballast which is deformed under train passage, but it would be costly to modify the existing ballasted track into such a structure. Generally, the track maintenance at least requires a minimum manpower for inspection etc. and therefore the maintenance-free structure should be realized at low cost with maximum exploitation of the minimum manpower.

Maintenance work is a sort of information system including the detection of defects, repair and check of restoration; and accordingly it is desirable to have a feedback loop which is rapid, accurate and cost-effective. On the Tokaido Shinkansen line (ballasted track) a computerized system which is an adequate combination of the processing of the high-speed track inspection car measuring data and farming out of repair work to the subcontractors has been established as an economical track maintenance system coping with high-speed mass transport.

3.1.2 Implementation of microelectronics(ME) into facilities

It is a feature of the railway that as the transport volume exceeds a certain magnitude, the transport cost per unit volume tends to rise. To reverse this tendency, an increased transport capacity must be balanced with a simplified facilities (wayside) and maintenance. Thus the research efforts must be focussed on "microelectronic" security system on the ground and "intelligent" train.

"Electronic" token security system for single-track section and electronic interlocking device on station premises are already working in practical service, contributing to the cost saving of railway operation. Meanwhile we undertake the development of an on-board track inspection system utilizing the image processing technology. Further we have embarked on the development of a new signal and security system in which the train and the system center are to play a major role instead of the wayside signals and thereby hasty investigation into the security of ME system involving software is being demanded.

High-density train service naturally entails crew expansion. For this reason, implementation of ME within the train is crucial. A monitoring system aboard the Shinkansen train and omission of guards on freight trains are already realized. Unmanned operation is technically feasible but the first thing to be done will be the winning of the social consensus in favor of it.

3.1.3 Multilateral exploitation of staff

Personnel which are scattered in the areas of railway operation and cannot be exchanged at short notice should be exploited as multilaterally as possible for the purpose of saving the expense. Dependence on unilateral specialists will inevitably result locally and temporally in wastefulness.

In this case, one man is expected to work concurrently in multiple professional positions and we are venturing on the development of a computerized expert system based on knowledge engineering. Immediate objects of study are diagnosis of tunnel, concrete structure or rotating machine; and monitoring of vehicle condition; and some achievements are practically being applied.

Shortening of the time taken for a new recruit to acquire a skill is effective in this respect and the expert system is considered equally useful for this purpose. As an aid to the train driver, the development of a navigation system is also underway.

3.2 Saving of materials expense

Here the problems are how to save the materials consumption for railway operation and how to extend the service life of installations.

3.2.1 Energy saving

Essentially the railway is a mode of transport which consumes comparatively little energy but the share of energy cost in the total operation cost is not insignificant. Power regeneration is an established technology already being put to practical use. Meanwhile we studied an energy-saving operation of the Shinkansen vehicle and as a result accomplished a 10 % cut of power consumption.

The actual state of combustion in the diesel engine has been scarcely known, but we could reveal it with use of optical fibers and now a 20 % saving of oil consumption through combustion control is expected.

3.2.2 Life extension of contacting/rotating parts

Contacting parts in railway installations often belong to boundary areas of engineering fields. It is therefore necessary for the best solution that the problem of extending their life be approached from both sides of the contacting parts. From this standpoint we are pushing the work on many projects which naturally include the improvement of bogie and pantograph so as to reduce the maintenance jobs of track and trolley wire.

Shelling cracks of the Shinkansen rails are one of the major subjects, which is likely to become an international theme in view of the railway tending to be lighter and faster.

3.2.3. Life extension of superannuated bridges

Apart from tunnels and roadbeds, superannuated bridges to be replaced threaten to impose a heavy burden on the railway economy which holds tremendous volumes of aged assets. We are trying to develop a method for extending the life of superannuated bridges so that they can be timely replaced without giving a fatal blow to the economy.

3.3 Saving of construction cost

The railway infrastructure, once laid, virtually defies any modification and its enormous investment proves to be a not insignificant drain on the railway economy which should be based on sound profitability. In the future railway construction a stringent position will have to be taken on this point.

Railway construction is practically impossible in urban centers where land development has highly advanced resulting in a spiraling land price. As a remedy, selection of a tunnel route at great depth of underground is being considered. Meanwhile a legislation is being drawn up to limit the private property rights to the surface layers so that the deep underground can be freely used in the public interest. Technological problems expected to arise in construction of such a deep tunnel are being identified and for this purpose a double-core shield which is deemed a promising tool for a large-section excavation has been developed and is already working practically.

As compared with the viaduct, the embankment costs less but it is a poor earthquake-proof structure and accompanied with a heavy land expense. We have tentatively set up a full-size model of an embankment which needs a land plot of only the same width of land as the viaduct on account of fiber-reinforced materials like geo-textile inserted between soil layers of a specified thickness, yielding excellent results.

In future a large scale of structure going up into the space above the permanent way may be necessitated for effective use of land and in this connection we are pushing ahead with the development of an inexpensive construction method calling for no underground girders difficult to be installed normal to the track. In the meantime we repeat test executions in quest of a low-cost execution technique, anticipating an increase of constructing an underground structure across the track in cases of eliminating the crossings, building an underpass.

A pending plan to lay additional Shikansen lines has lately been authorized, but traffic demand on the new lines is expected to be low and it may become necessary anytime to start research and development for drastic cutting of construction cost.

4. SAFETY AND RELIABILITY OF RAILWAY

The urgent task demanding attention in the research and development efforts of the railway is upgrading of railway function and cutback of railway cost, thereby contributing to the railway economy, but here the overriding condition should be that the safety and reliability of transport are guaranteed. In the challenging tasks involving a tough technical breakthrough, the greatest weight should also be attached to this condition.

It should, however, be noted that the accident is after all a sort of quantifiable probabilistic phenomenon and we should stick to a "cool-headed" attitude that safety is a service quality we can offer the passengers after overcoming the cost burden. We pay due attention to the study on the human error which constitutes a vital element in the safety problem.

Next we refer to several works motivated by peculiar circumstances of Japan.

4.1 Earthquake

At present, tremor-sensors are installed along the Shinkansen line (on the Pacific coast far from the track in the case of Tohoku and Jo-etsu Shinkansen lines) and they issue alarms upon sensing a major tremor of earthquake; but they lack somewhat in rapidity of alarm and applicability of information.

A seismic detection system capable of detecting a seismic motion at the initial microtremor stage (P-wave) and at the same time automatically determining the seismic scale and source in a few seconds has been devised and perfected to a practically applicable extent. Further we are venturing on the development of a comprehensive system which is capable of making a timely decision to resume the train operation after a seismic warning is issued and automatically pinpointing the hit areas within a few minutes, and consequently helping the restoration to normal traffic.

4.2 Snow (with respect to high-speed train run)

On the Jo-etsu Shinkansen line operating in the snowy region plagued by more than 3 m deep snowfall, warmed water has been sprayed to melt the snow as it falls on the ground, but saving the energy consumed to heat up the circulated water poses a difficulty. As a countermeasure an attempt is being made to obtain the warmed water utilizing the summer heat of the sunbeam and store it undergound, to be used in winter.

On the Tohoku Shinkansen line where the snow deposit is not so deep, the snow-plow harnessed to the train head is mainly used to eliminate the snow, but when the deposit exceeds a certain depth, manual snow removal work becomes necessary and for this purpose, snowfall forecasting is made a subject of research and development.

On the Tokaido Shinkansen line, the problem of disrupted operation due to snow accretion to the vehicle in snowfall is not yet completely solved. Such a sorry state on the Shinkansen enjoying the greatest patronage in Japan must by all means be liquidated. We intend to attack the problem in real earnest, fundamentally delving into the snow accretion mechanism.

4.3 Crossing

In Japan the limited flat plains are inhabited with dense population and both highways and railroads, running through them, naturally abound in crossings with heavy traffic. When the conventional railway system is to be drastically transformed, we encounter a bottleneck in the form of crossings involving safety problem.

We are vigorously attacking the problem from two aspects: human engineering approach to roadway users; and maximum implementation of ME technology for crossing protection facilities. To cite a few examples, we are experimenting with a specified ringing duration of the crossing alarm regardless of train speed and with an all-weather type crossing obstacle detection system to be installed in snowy regions where neither the optical beam nor the laser is available.

5. APPROACH TO THE FUTURE SOCIETY

Another perspective along which we can promote the research and development for railway is adaptation of the railway system to:

a) information-oriented society;
b) "graying" society; and
c) diversified society to come after the present industrial society

This attitude will not only make the railway system itself turn to the information system; accommodate the demand of elderly people; and meet the diversified needs, but also it should result in that:

1) rail transport (flow of people and materials) and information flow are optimized by complementing each other;

2) the information systems inside and outside of train are integrated; and

3) the railway goes into non-rail communities by utilizing its own facilities.

Particularly concerning 3), it is conceivable that the railway extends its services to the wayside communities by utilizing, say, the information carrier channel (optical fiber) stretched along the line and its accessories; or the multifunctional station facilities are assigned to serve as a new functional center of the peripheral communities. These ideas will make intriguing subjects of investigation in future.

Such an attitude of the railway to the future society is believed to be always consistent with humble commitment to environmental preservation.

6. CREATION OF NEW TYPE RAILWAY

The Fourth Comprehensive National Development Program formulated by the Japanese Government in 1987 stresses correction of Tokyo-centrism and nationwide balanced development and sets the ultimate target at a multi-polar scattered pattern of national land development. For this purpose, it proposes establishment of a transport network which will bring all the major cities into a mutual link-up in a one-day trip zone.

Such a grandiose proposal seems to presuppose the advent of a novel mode of transport surpassing every means of land transport ever invented by the humans. It must be just the so-called "superspeed guided ground transport system" which transcends the category of the steel rail/wheel system.

The defunct JNR had struggled for creation of a novel type railway since 1962. Taking over from the JNR, the reorganized Railway Technical Research Institute is now assuming the responsibility for the development of the next-generation guided transport system based on linear synchronous motor drive, superconducting magnetic repulsive levitation and guidance.

On a 7 km long test track at Miyazaki, we were already successful in a superspeed levitated run at 517 km/h; a manned levitated run at 400 km/h;

and in a run of three-car train at 362 km/h, demonstrating the feasibiligy of the system as a superspeed means of land transport. Up to this time we have logged 66 thousand km of run and successfully carried 12 thousand passengers on test runs; the test run is being continued.

On the other hand, we have finished various tests such as a run through a provisional constructed tunnel; a run over an irregular guideway; a cross-over run to substations; an emergency landing on the ground; a drag-braked run. We are now conducting the tests such as a test of turnouts; a long-term reliability test of superconducting magnet and vehicle-mounted refrigerator under electromagnetic forced vibrations; a test of the on-board magnetic shield.

Meanwhile we perform a siting survey for the construction of a longer test track extending several tens of km at the request from the Government. On this longer test track we intend to make a variety of practical tests: a superspeed long-time run; passing each other of two trains on a double track; train passage through a tunnel; runs over curves and gradients; multiple train control; checking of durability and reliability; personnel training in operation and control.

Imaginable applications of a superspeed transport system at a maximum speed over 500 km/h are as follows:

1) Urban transport linking cities with one another in one to three hours over a distance of 500-1000 km, which is one of the "transportation gap" as pointed out by Bouladon. Competition with other modes of transport will pose a problem here.

2) Commuter transport linking the urban center and the residential zone separated from each other by about 160 km/h in a sprawling urban zone. Here we see no competition from other modes of transport.

3) Access transit linking the airport to the urban center (several tens of km away). This will be a shuttle service taking several minutes. Being a terminal accessory (horizontal high-speed elevator) rather than a transport means, it may have its economy included in the terminal operation expense account.

At the Railway Technical Research Institute, a linear thyristor(DC) motor-driven, pneumatic tyre-supported guided system as still another future version of guideway transport system(ALPS) is under development. Capable of developing a maximum speed of 160 km/h with low noise and negotiating a steep gradient, it will be fit for commuter transport over a distance of about 100 km and for access to the airport.

Relying on the linear thyristor(DC) motor propulsion coils for levitation, it will ease the burden on rubber tyres and contribute to the speedup over 200 km/h.

Since the construction of these new railways embraces a strong element of national land development, it will deserve the support from the Government.

7. CONCLUDING REMARK

What the railway technology should be like in the near future and what the Railway Technical Research Institute should tackle with in line with the policy are reviewed. The research and development activities of the Institute have so far been implicitly and explicitly hampered by the conservative mentality of the railway community nurtured in the long history of its prosperity. With a clean break with the past, we are embarking on the creation of a novel form of railway system. This, we believe, will be instrumental to revolutionizing the progress of railway technology.