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Railway Division

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MODERN STEAM - AN ECONOMIC AND ENVIRONMENTAL ALTERNATIVE TO DIESEL TRACTION

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MODERN STEAM - AN ECONOMIC AND ENVIRONMENTAL ALTERNATIVE TO DIESEL TRACTION

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1. INTRODUCTION

More than 30 years have elapsed since a paper on steam locomotive development was presented to the Institution of Locomotive Engineers. Whilst that paper [1] given by Mr. L. D. Porta in 1969 was directed to the traction requirements of the under-developed countries, this paper suggests a fresh look at *modern steam* as a potential alternative to diesel traction mainly in the first world. This strong statement is based on practical experiences gained over the last 11 years whereby *modern steam* traction has compared favourably with diesel traction.

Since 1969, steam traction has seen ups and downs, but the general tendency has been that of decline. However, during the oil crisis in the 1980's, steam power was reconsidered by many railways, recognising its inherent advantage in its ability to burn most types of fuel. Even in the USA, steam traction was seriously looked at, resulting in several ambitious projects including ACE 3000 [2]. When the oil price dropped again, these projects were terminated at an early stage of development. Nevertheless, several other projects have been realised in countries with abundant, cheap coal, amongst which was the rebuilding of 89 Garratt locomotives in Zimbabwe [3]. It incorporated the conversion of all axles to roller bearings, but otherwise the design was left unchanged. The rebuilt Garratts replaced diesel locomotives, saving oil and money.

In South Africa, steam locomotives were developed under the direction of David Wardale, who employed Porta's technology to rebuild 19D class light 4-8-2 No.2644 and 25NC class heavy 4-8-4 No.3450 [4]. The author has been involved in testing the latter. However this decision to leave the Swiss Locomotive and Machine Works to work on steam locomotive development was based on interest rather than intentions. Like most people I thought that steam locomotives were fascinating, but inefficient, polluting and old-fashioned. This attitude changed with the insight of an economic traction study done by the South African Railways in 1981 for the mainline from Kimberley to De Aar [5], whereby the 30 year old 25NC class steam locomotives proved to be more economical than both the newer 34 class diesel locomotives and the 7E electrics. The rebuilt No.25NC 3450 was the most economic of all. This unexpected result proved that steam locomotives were not a priori uneconomical, but it did not change the long-term traction policy of SAR. The drive to be "modern" was stronger than the aim to optimise the economics. Realising this meant that steam locomotive development has to be done in the first world, if it is to be seriously considered by normal commercial railways. Switzerland, with 99 % of its railway lines electrified, was certainly the most unlikely place for steam locomotive development and therefore ideal for the desired effect. With one steam railway only, the choice of where to propose modern steam locomotives was not too difficult!

At that time the only steam operated railway in Switzerland, the Brienz-Rothorn Railway, was about to purchase yet another diesel locomotive. Diesel traction had been introduced in 1973, when a solution had to be found to improve the economics and increase the traffic capacity. The old steam locomotives could no longer cope with the demand and were expensive to operate. In 1970 a traction committee therefore investigated alternatives, carefully looking at all traction modes. The recommendation was for diesel-hydrostatic locomotives and lightweight coaches. The first diesel locomotive No. 8 was not quite up to the expectations, but provided a basis for a much better version built in 1975. Locomotives No. 9 and 10 are capable of handling 112 passengers with a driver and a guard, whilst the old steam locomotives transport 48 to 80 passengers only and require a fireman.

Rolling Stock of the Brienz-Rothorn Railway from 1975 to 1986						
Engine No.	Type	Built	Coaches	Seats	Train Crew	"Productivity"
1...5	Steam	1891/92	1	48	3	100 %
6, 7	Steam	1933/36	2	80	3	167 %
8	Diesel	1973	1	48	2	150 %
9, 10	Diesel	1975	2	112	2	350 %

Table 1: Rolling Stock of the Brienz-Rothorn Railway from 1975 to 1986. "Productivity" relates to the number of passengers per train crew member in relation to the oldest steam train.

This situation left the railway with a dilemma - most passengers wanted to ride in steam trains, but capacity and economics forced the railway to prefer diesel traction. The result was a continuous decline in the number of passengers that were actually transported by steam traction. Many passengers were dissatisfied and complained. The author thought it was time to present a better alternative and proposed modern steam locomotives that would be as economical as the diesels and as attractive in interest as the old steam locomotives. Fortunately the director of the Brienz-Rothorn Railway was interested, but it turned out to be more difficult to convince the management of the Swiss Locomotive and Machine Works to take up the production of steam locomotives again, which had been terminated in 1952. Indeed the first design proposal as well as the first meeting with the director of the Brienz-Rothorn Railway were done in spare time, with kind permission of SLM. Many internal discussions followed, but in the end the SLM management proposed to leave the decision to the results of market research. Six or more new rack steam locomotives would mean the go ahead. If the call was for less, the file on new steam locomotives would be closed for good.

The market research revealed a demand for no less than 15 new steam locomotives, more than anyone had expected. The Brienz-Rothorn Railway opted for two, the electrified (!) Montreux-Glion-Rochers-de-Naye Railway for one and the Austrian Federal Railway for 12, six each for the rack lines on the Schafberg and the Schneeberg.

2. SHORTCOMINGS OF OLD STEAM POWER

Most comparisons between steam, diesel and electric traction ignored a considerable age difference and were therefore neither balanced nor fair although it cannot be denied that old steam locomotives did indeed have shortcomings. These are still well known and therefore only briefly mentioned:

- High footplate staff costs due to the fireman
- High maintenance costs (on account of the old age or obsolete constructional practice)
- Low thermal efficiency resulting in high fuel consumption
- Smoke and air pollution due to incomplete combustion
- Risk of line side fires due to spark emission
- High stand-by losses due to lack of insulation of boiler, steam pipes and cylinders.
- Extensive servicing necessary for taking coal and water, preparing and cleaning the fire, emptying ashpan and smokebox, washing out the boiler
- No interchangeable parts

To overcome these shortcomings in order to compete against diesel and electric traction, a thorough analysis was done. It was found that the majority of deficiencies were dictated by the use of outdated technology and constructional practice. The conclusion was that employing modern technology would allow economical and clean steam traction.

3. ADVANTAGES OF MODERN STEAM POWER

New steam locomotives that are economically and ecologically competitive need to have the following advantages:

- One man operation
- Light oil firing with excellent combustion
- Higher thermal efficiency
- Full insulation of boiler, cylinder and steam pipes
- Quick start-up
- Minimum servicing requirements
- High mechanical efficiency
- No leakage of lubricating oil
- Interchangeable parts

It was soon clear that an entirely new design was needed to achieve all these technical improvements. Rebuilding of existing old rack steam locomotives would not be appropriate and was not even discussed. It was also clear that the entire train operation had to be looked at. The aim was to match the latest diesel locomotives of the Brienz-Rothorn Railway and to outperform the diesel railcars of the Schafberg Railway. This was by no means an easy task, as the last two diesel locomotives of the Brienz-Rothorn Railway performed exceptionally well and the railcars of the Schafberg Railway had given quite good service.

To improve the economics, more passengers must be carried with fewer personnel. This called for a new concept.

4. ECONOMICAL OPERATING CONCEPTS

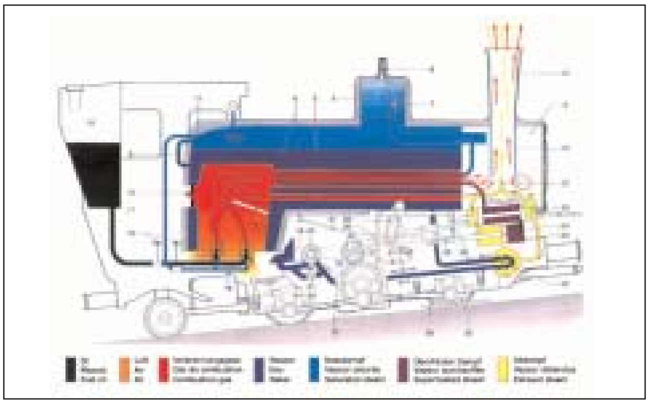
The century-old track of the Brienz-Rothorn Railway restricts the train weight to 32 tons, which meant that an increase in the number of passengers required minimal weights of the locomotive and the coaches. The existing coaches were already of excellent lightweight construction, weighing 3.1 tons for 56 seats and 4.0 tons for 60 seats respectively. According to the Swiss norms, average passengers weigh 75 kg. The aim was to take the two heavier coaches with 120 passengers up the 1 in 4 inclines of the Brienz-Rothorn to outperform the diesel trains seating 112 passengers meant a service weight of a mere 15 tons for the engine. Compared to the latest steam locomotives of the Brienz-Rothorn Railway built in 1933 and in 1936, the weight of the new engines had to be reduced by 5 tons, whilst the power had to be increased considerably to attain the higher speed envisaged. This consequently required application of the principles of lightweight design and the use of new materials previously unknown in steam locomotive construction. Of course, lightweight design requires careful engineering and additional calculations. Table 2 shows a comparison of the weight per seat and proves the excellent relative position of the new rack steam trains. Only the last series of diesel locomotives of the Brienz-Rothorn Railway are slightly better in this respect. Railcars, either diesel or electric, have a much higher weight per seat, a fact that is not commonly realised. Less weight per seat also means reduced energy consumption, especially on mountain railways. The actual energy consumption per passenger round trip is much more important than a maximum efficiency achieved at a specific load on a test bed.

Comparison of the Weights per Seat on Rack Railways			
Railway, max. Gradient	Train	Seats	
Train	Weight	No.	Weight
Brienz-Rothorn Railway, 250 ‰ (1 in 4)			(per seat)
Diesel locomotive No. 9 - 11 + 2 SIG - Coaches	19'400	112	173
Steam locomotive No. 12, 14, 15 + 2 SIG - Coaches	21'200	112	189
ÖBB Schafberg Railway, 250 ‰ (1 in 4)			
Steam locomotive 999.201 – 204 + 2 ÖBB - Coaches	24'800	105	236
Diesel railcar 5099.001, 002	25'700	77	334
NÖSBB Schneeberg Railway, 200 ‰ (1 in 5)			
Steam locomotive 999.201 + 2 Bombardier - Coaches	23'800	110	216
Diesel No. 11 – 13 + 2 Coaches No. 21,22; 31, 32	32'150	120	268
Snowdon Mountain Railway, 200 ‰ (1 in 5)			
Diesel railcar No. 21 - 23	15'250	41	372
Diesel locomotive No. 11 – 13 + 1 Coach No. 2 – 8, 10	25'200	56	450

Table 2: Comparison of the train weights per seat on rack railways. All weights are in kg. The number of seats on the diesel railcars 5099.001 and 002 have been reduced from 77 to 70 in 2001 for fire safety reasons.

5. TECHNICAL DESCRIPTION

As can be seen from figure 1, the basic layout of the new steam rack locomotives has remained classical, albeit with many design improvements.



The following is not a full technical description and is limited to the innovative features of the new rack steam locomotives:

5.1 One-Man Operation

The new steam locomotives are operated without a fireman, reducing footplate staff costs to the level of diesel and electric traction. One-man operation is facilitated by the fact that the trains are pushed. Consequently line observation when climbing is assured by the guard riding up front, leaving the driver to concentrate on his engine. When running downhill the driver has to observe the track ahead; on the other hand the boiler requires no attention then. Nevertheless various improvements ensure that the driver is not overtaxed with his dual responsibility of driving and firing:

- **Oil firing:** Compared with hand firing of coal, oil firing saves a lot of work. Moreover a newly developed compound governor enables the firing rate to be controlled with one hand.
- **Boiler feed pump:** There is a mechanically driven feed pump for feeding the boiler while in motion. The feed rate is controlled by means of a throttle valve.
- **Mechanical lubrication:** The driver does not have to worry about lubrication while running. Lubrication is carried out in the shed at intervals.
- **Vigilance systems:** Vigilance pedals are provided for safety protection.

The task of driving the new steam locomotive is nevertheless more challenging (and interesting) than driving a diesel locomotive. Eleven years of experience show, however, that the one-man operation is safe and works very well.

5.2 Oil firing

Oil fired steam locomotives are not new, but most of them burned heavy fuel oil. For the new rack locomotives this was ruled out. Heavy fuel oil has to be preheated for filling-up and firing, necessitating heating coils. This means more weight and extra energy consumption. The high sulphur content (>1%) is detrimental to the environment and to boiler life (corrosion). Since heavy fuel oil is used by major industries it is difficult to obtain in tourist resorts, whereas light oil, also used in domestic heating, is easy to get.

The decision to go for light oil meant that a new firing system had to be developed, as there were no suitable models on the market. The main problem was to achieve complete combustion in the small firebox. The advantages of designing anew were exploited by enlarging the firebox volume significantly. On account of the overall dimensions and the weight limit, however, there was no room for a combustion chamber. Therefore the quantity of fuel delivered had to be divided to shorten the length of the flame. In view of the almost square firebox shape, four main burners were provided to achieve a uniform firebox loading. To ignite the main burners there is a pilot burner located in the middle. The pilot burner is also used for stand-by and shunting. All burners fire vertically upwards. The flames do not touch the firebox. This is essential for optimal emission values.

In view of the new concept it was decided to test the oil firing while the locomotives were being built. The first boiler was given a specially designed superheated steam collector from which steam was discharged to atmosphere after passing through a stable throttle valve. The amount of exhaust steam could thus be adjusted, maintaining conditions with the regulator wide open. Draught was produced with a blower, enabling the lowest amount of excess air to be established.

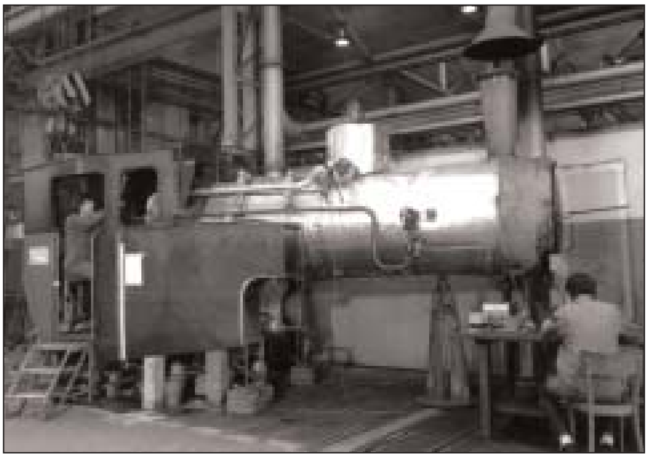


Fig. 2: Test stand for the new light oil firing. The boiler is provisionally insulated. The cab is a mock-up.

Development work in its truest sense was necessary to tune up the oil firing system to the required standard. With the first attempt (figure 3), the combustion was awful, producing a lot of smoke. The air flow around the burners had to be changed radically (figure 4). With these and other modifications, very clean combustion was then achieved.

Fig. 3: Oil firing system as delivered.

Fig. 4: Oil firing system after the tests.

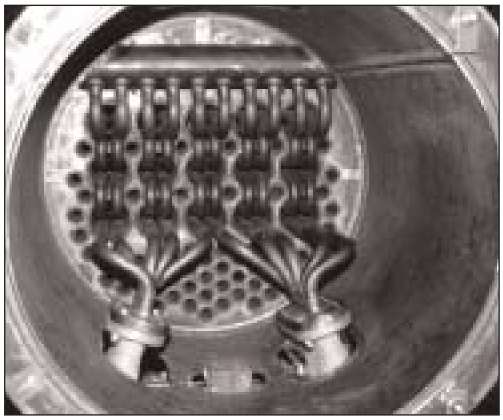


Fig. 6: All-welded light weight superheater.

5.3 Boiler and Superheater

Oil firing and the weight limitations dictated an all-welded boiler with a steel firebox (figure 5). The inner and outer fireboxes are joined by the U-shaped foundation ring and thread-less hollow stay bolts. The boiler is bolted to the cylinder block at the smoke box and rests on two swing plates at the foundation ring to allow for thermal expansion.

Special care was necessary to secure an adequate water level over the firebox crown at all inclinations over which the locomotives are worked, from level up to gradients of 250 ‰ (1 in 4). As a safeguard, an electronic low water alarm system shutting off the oil flow by means of an electromagnetic valve is provided. It replaces the fusible plug usual with coal firing.

For feeding the boiler, the century-old system of the mechanical feed pumps was "re-invented" in a modern form. The feed pump is belt driven from a toothed wheel on the crankshaft. The feed pump delivers the feedwater taken from the side tanks via an exhaust steam feedwater heater to the check valve. The water supply is controlled by means of a bypass valve easily operated by the driver. When not in motion, the non-lifting injector is used. The boiler has no steam manifold. Auxiliary steam is extracted directly at the dome. The regulator fitted in the dome is a commercial valve which allows finely graduated operation thanks to its special geometry. After the regulator the wet steam passes through the regulator pipe, before being delivered to the superheater.

Initial thermodynamic boiler calculations showed that superheating with elements in six series stages is necessary to achieve the desired steam temperature of 420°C. This called for the special arrangement of the superheater elements (figure 6). The superheated steam is led directly to the cylinders.

Fig. 5: Construction of the boilers.

5.4 Efficient Boiler Insulation

Even in heavy traffic conditions the locomotives operate only 8 to 10 hours per day, the rest of the time they stand in the shed. To save energy and staff costs, the boiler has very efficient insulation and stays in steam overnight, the oil firing being shut off. With a boiler pressure of 6 to 9 bar on the following morning, the pilot burner is lit and the locomotive is ready for service immediately. The electric preheating device is needed only after a boiler wash-out or a long period out of service.

In the past energy losses by radiation were grossly underestimated by most railway engineers. Admittedly 3 to 5 % of the maximum evaporation does not seem a lot, but in terms of energy, 20 kW for small, 50 kW for medium size and more than 100 kW for large European locomotives used to be constantly radiated from traditional boilers and fittings all the time the engine is in steam. If a main line locomotive is in steam for say 300 days a year, the energy losses by radiation amount to 300 x 24 h x 100 kW = 720,000 kWh per year, not really negligible. Considerable amounts of energy can thus be saved by proper insulation. The state of the art can be derived from standards applied to industrial boilers, where the importance of optimum insulation was recognised much earlier. Whilst on coal fired locomotives, some of the energy saved by proper insulation will be lost by increased blowing off at the safety valves for lack of fine modulation of the coal fire on the grate, the insulation of oil fired boilers cannot be too good.

5.5 Steam Engine and Valve Gear

The steam engine is a classical two-cylinder simple expansion engine with Walschaerts valve gear. Numerous improvements have been realised compared with earlier designs:

- enlarged steam chest volume
- straight steam ports
- minimal clearance volumes
- reducing power absorbed in exhaust back pressure
- optimised blast pipe
- generous valve travel

The welded double cylinder unit has cast-iron liners. The piston valves are guided on both sides, with the front guide inside. They have 7 narrow rings per valve head, ensuring good steam tightness. The piston with piston rod is of all-welded lightweight design. To connect the piston rod with the crosshead, a design based on American practice was chosen.

The rods and valve gear have been kept as bright as possible and matt chromed to inhibit corrosion. Reversing is done by hand wheel from the cab.

To enable the steam engine to operate within its economical speed range, the locomotive has an intermediate gear in the final drive with a reduction ratio of about 2.3 : 1.

5.6 Frame, Springs and Drive

The all-welded frame had been designed following the principles of lightweight construction, necessitating FE-calculations. Leaf springs are used for the locomotive suspension.

The crank pins on the large gear wheels drive the two road axles through the front and rear coupling rods. The driving axles to the rack are supported in their bearings and in the supporting road wheels. The tractive force is transmitted solely via the driving pinions which engage in the rack. These are sprung in the direction of rotation to compensate for pitch errors in the rack. On account of weight the driving axles have hollow shafts.

The hind truck is of the classical bissel or pony type. The support is via leaf spring through a carrying roller, which turns on a slightly V-shaped plate. This arrangement allows perfect centering while travelling on the straight and good curve negotiation thanks to the moderate centering effect. To minimise rolling the hind truck is equipped with a stabiliser.

5.7 Adaptability to Gauge and Rack Systems

Rack railways employ a variety of gauges, rack types and electric power systems, so that standardised motive power to get an economy of scale in production is difficult to achieve. The steam locomotive has inherent advantages, which have been exploited. Gauges from 800 mm (Brienz-Rothorn, Montreux – Glion – Rochers-de-Naye) to metre gauge (Schafberg, Schneeberg) are accommodated by merely altering the disks of the wheels (figure 7). The height of the rack above the rail is accommodated by the varying diameter of the road wheels.

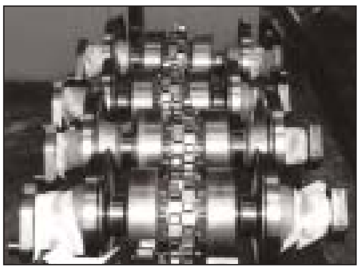


Fig. 7: Driving axles for 800 mm and metre gauge. Note the wheels, the centres of which are simply turned to accommodate the difference in the gauges. All the other parts are identical.

5.8 Brakes

The locomotives are equipped with three independent brakes:

- A Riggenbach counter-pressure brake serves as a wear-free service brake. The steam engine then acts as a compressor, the valve gear being set against the direction of travel. In the braking process heat is generated, which is converted into steam by injecting cooling water. The braking action can be controlled by means of a throttle valve. To reduce the hissing noise a silencer, integrated in the rear buffer, is provided.
- Mechanical brake system I is a spring-operated brake actuated by compressed air. Locomotive and coaches each brake their own masses proportionally. Brake system I is normally operated by the driver. All emergency brake applications act on brake system I via electro-pneumatic valves.
- Mechanical brake system II is concentrated on the locomotive and is able to stop the entire train without the assistance of the coach brakes.

5.9 Exhaust System

Initially three exhaust systems, all of proven efficiency, have been evaluated: Kylchap, Giesl and Lempor. For reasons of simplicity, weight, availability of the calculation method and optical appearance, a single Lempor draught apparatus was chosen. The original design with four nozzles was simplified to one nozzle only. All parts are made of stainless steel thereby eliminating corrosion.

When some of the Austrian drivers complained about the noise in the cab at full power, an analysis showed that sound absorbtion in the cab would not be sufficient and a silencer on top of the chimney would spoil the looks and foul the loading gauge. By slightly increasing the angle of the diffuser part of the Lempor exhaust, the height of the chimney could be reduced without reducing the draught, a silencer in the shape of a “Kobel” spark arrester could be fitted. Such spark arresters were quite common in Austria on coal and wood fired steam locomotives. The “stack talk” is thus reduced by 6 dB(A) and not all passengers like the whispering sound, but the drivers are happy.

5.10 Electrical Equipment

The locomotive is equipped with a modern electronic safety and emergency brake control system. Batteries are provided for the locomotive’s current supply. These are charged via a mechanically driven alternator while running and in the shed through an external battery charger as necessary. Apart from the alternator and batteries, all electrical equipment is in the rear of the cab, separating the electrics from steam equipment.

5.11 Safety provisions

One-man operation of the locomotive and the strict regulations for rack railways dictate comprehensive safety provisions:

- Vigilance systems pedals with quick and slow action
- over-speed trip
- roll-back protection

All monitoring functions, speed and distance displays and recording are provided by the electronic TELOC 2000 S unit.

5.12 Electric Feedwater Preheating Device

To improve the operational readiness of the new steam locomotives and to save man-hours for preparation, an electric preheating device was developed. A ‘cold’ locomotive can thus be put in steam or a ‘warm’ locomotive can be kept in steam without supervision.

The principle of operation is quite simple (figures 8 and 9): Water from the boiler flows by gravity to the circulation pump, which forces the water through the electrical heater back into the boiler. The forced circulation causes extremely uniform heating, because the entire boiler is heated from the water side and therefore has the same temperature everywhere - unlike conventional warming-up, which heats the firebox and the tubes first while the outer firebox and boiler barrel are still cold. The electric preheating device warms up the water slowly to the temperature set on the control thermostat.

Fig. 8: The electric preheating device can also be used for coal-fired steam locomotives, considerably reducing the amount of smoke produced during lighting up. Neighbours are delighted.

Fig. 9: Two flexible hoses connect the boiler to the preheating device. Note that the hoses can only be disconnected if both ball valves are shut. This ensures that the preheating device cannot be disconnected under pressure.

The preheating device for the new rack steam locomotives, which have fully insulated boilers, is rated at 25 kW only. When starting with cold boiler water, it takes 12-16 hours to reach a pressure of 10 bar. The intention is to preheat a cold locomotive overnight, so that the locomotive is in steam the next morning. Before moving the locomotive, the preheating device must be detached. Switching it off and disconnecting the two flexible hoses takes five to ten minutes.

If the preheating device is used to keep a locomotive in steam or just warm, the desired temperature can be selected with the control thermostat, which maintains the set temperature within +/- 5°C by switching the heating on and off. A safety valve and a second thermostat prevent the maximum pressure or temperature being exceeded in case the control thermostat should fail.

6. WORK LOAD TRIALS

The fact that the "last" steam locomotives had been built by SLM in 1952, and the abundance of technical innovations made works trials advisable. The concept of employing a second steam locomotive as brake locomotive made it possible to build an attractive, low-cost test stand. The two locomotives were set up on inclined ramps and coupled by means of a Cardan shaft (figure 10). Whilst one locomotive was driving, the other one was retarded by means of the counter-pressure brake.

First the locomotive No. 12 of the Brienz-Rothorn-Railway was put on the test stand and instrumented with the measuring equipment. Five days later, the first revolutions under steam took place. Everything went right from the start. When the second locomotive, No. 999.201 of the Austrian Federal Railways was ready, the tests began. Even under load there were few problems. The main tasks were to tune the draughting to the oil firing for optimum combustion and to take electronic indicator diagrams to check the valve events and determine the power. The measured results were better than calculated.

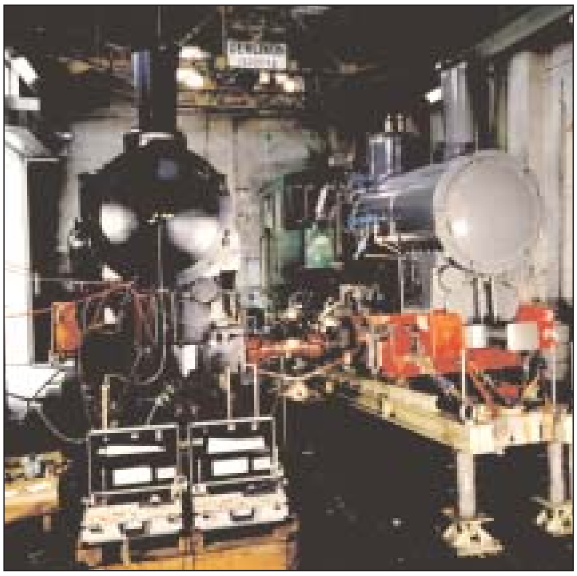


Fig. 10: Work load trials at SLM with locomotive No.12 of the Brienz -Rothorn Railway on the left side and 999.201 of the Austrian Federal Railway. The two bright cases in the foreground contain the emission analysers.

7. EMISSIONS

Traditional steam locomotives cannot claim to be particularly environment-friendly. Our intention was to change this with the new light oil firing system and to achieve clean combustion, but no more than that. We measured the emissions mainly to determine the quantity of excess air. Only when we realised how good the values actually were did we get more ambitious and attempted to find the optimum. We then thought it worthwhile to compare the measured emissions with the ones of the latest diesel of the Brienz-Rothorn Railway. Because diesel locomotive No. 11 was five years older than steam locomotive No. 12, the manufacturer of the diesel engine was asked to provide the cleanest actual emission data. For the sake of a truly fair comparison, No. 11 was thus "equipped" with data from the latest diesel engine. The measured emission values were then calculated in relation to the power at the rack driving pinions. A mountain railway cycle, consisting of 10 % stand-by, 45 % uphill and 45 % downhill working was used for comparison of the total emissions per round trip. The diesel locomotive benefits from its higher thermal efficiency, which is partly offset by the ability of the new steam locomotive to go downhill with the oil firing shut off. The result of the comparison can be seen in figure 11.

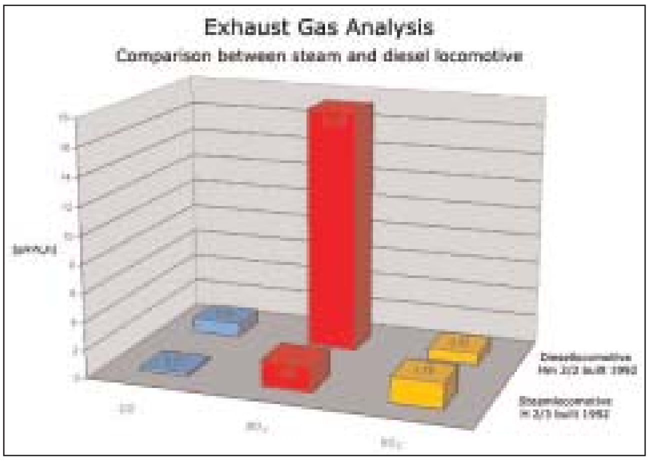


Fig. 11: CO-, NOx- and SO2-Emissions for diesel and steam locomotives on a mountain railway cycle.

If steam locomotives had always been treated with the same fairness in former comparisons as we have treated the diesel locomotives here, steam traction might have lasted longer.

8. OPERATING EXPERIENCES

Thanks to the good basic concept, an abundance of calculations, the preliminary testing of new components on other locomotives, the development of the oil firing on the test stand and the extensive testing and instrumentation in the works, the new steam locomotives worked straight away and went in to revenue service soon after delivery. Of course there were teething troubles too, but these did not interfere with the daily operation. Modifications were made when the engines were out of service due to boiler wash-outs or in the winter, when the railways do not normally operate.

Fig. 12: Locomotive No. 12 of the Brienz Rothorn with 120 passengers just outside Brienz. White exhaust steam can be seen thanks to the cold outside temperature.

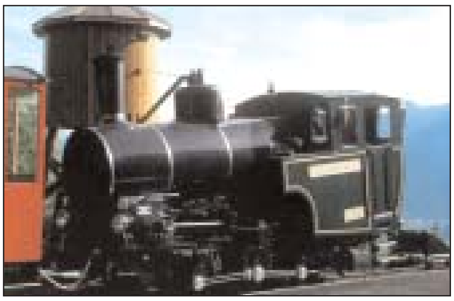


Fig. 13: Locomotive No. 1 of the Montreux – Glion – Rochers-de-Naye at Caux on its separate, non-electrified track. The rest of the line is electrified. Note the American style water tower with integrated fuel station.

Fig. 14: Locomotive No. 999.201 of the Schafberg Railway with a full load of passengers on 1 in 4 grade. Note the clean combustion at full load.

The good technical and economic results led to an order for a further lot of five modern rack steam locomotives. In 1996, two locomotives were delivered to the Brienz- Rothorn Railway and three to the Schafberg Railway. These locomotives are almost identical to the prototypes, the main modification being a lighter crosshead. With hindsight this modification was not really necessary.

Fig. 15: Environment-friendly transport of environment-friendly products. Two brand new rack steam locomotives built in 1996 for the Schafberg Railway, ready to be sent by rail transport

9. STEAM – DIESEL – STEAM

Diesel traction had been introduced to the previously all steam operated railways on the Brienzer-Rothorn and the Schafberg to increase traffic capacity and to reduce operating costs. The old steam locomotives remained in service, but less and less passengers were transported by steam trains. Figures 16 and 18 illustrate that the introduction of modern, economic steam locomotives led to a reversal of this trend:

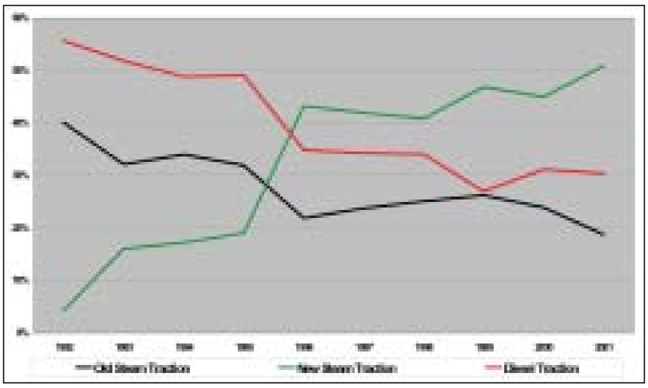


Fig. 16: Brienz-Rothorn Railway: Modal split between old steam traction, diesel traction and modern steam traction from 1992 to 2001. The percentages relate to actual mileage multiplied by seat capacity.

On the Brienz-Rothorn Railway the percentage of passengers hauled by diesel traction has been reduced from 70 % before the new steam locomotives were introduced to now only 30 %.

In 1996 the prototype diesel locomotive No. 8 was sold. Diesel locomotive No. 9 is relegated to works trains whereas No. 10 is on stand-by and helps out in peak traffic. Only the latest diesel locomotive No. 11 is still used regularly. The rolling stock now consists of:

Rolling Stock of the Brienz Rothorn Railway as from 1996						
Engine No.	Type	Built	Coaches	Seats	Train Crew	Productivity
1…5	Steam	1891/92	1	48	3	100 %
6, 7	Steam	1933/36	2	80	3	167 %
9, 10	Diesel	1975	2	112	2	350 %
11	Diesel	1987	2	112	2	350 %
12	Steam	1992	2	112	2	350 %
14, 15	Steam	1996	2	112	2	350 %

Table 3: Rolling Stock of the Brienz-Rothorn Railway as from 1996. Productivity relates to the number of passengers per train crew member in relation to the oldest steam train. The locomotives No. 11, 12, 14 and 15 are also capable to haul two heavier coaches seating 120 passengers. There is no No. 13!

Thanks to the new steam locomotives, the total number of passengers has increased considerably. In the ten years before the introduction of the new steam locomotives, the Brienz-Rothorn Railway carried 1,585,645, in the ten years with the new steam locomotives, 1,869,290 passengers, an increase of 18 %. This required only 3% more train journeys, a result of the higher capacity of the modern steam trains.

Railways are usually reluctant to release figures of their operating costs. Several attempts to get these from electric rack railways remained unsuccessful. We are therefore very grateful to the Brienz-Rothorn Railway to have released their figures, which allow one to compare the respective operating costs of old steam, diesel and modern steam traction on the same line and the same staff.

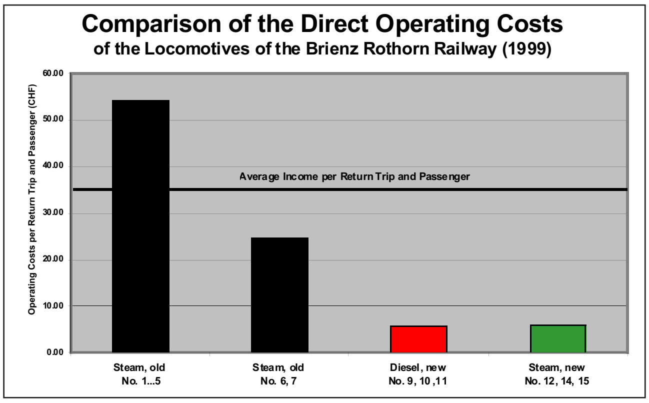


Fig. 17: Comparison of operating costs per passenger of old steam locomotives, diesel locomotives and modern steam locomotives in relation to the average income per passenger. The operating costs include all costs for staff, maintenance, fuel, water and lubricants.

Figure 17 shows clearly why the Brienz-Rothorn Railway preferred to use diesel locomotives before new steam locomotives were introduced. In Switzerland there is not only competition amongst the many rack railways, but also an overabundance of cable railways and aerial ropeways. This limits the ticket prices. With the price level more or less fixed and considering the fact that tourist railways are not subsidised, the operating costs have to be competitive, or else the railway will close. If the oldest steam locomotives are used, the income doesn't even cover the operating costs, so that the railway loses money on each passenger. By using either new steam or diesel locomotives, most of the income remains to cover capital costs, track maintenance, overheads and all other costs. Figure 18 proves what had been claimed when the new steam locomotives were introduced: the shortcomings of the traditional steam locomotives are a matter of old age and design concept and can be overcome by employing modern technology.

On the Schafberg Railway traffic is now almost entirely in the hands of the modern steam locomotives:

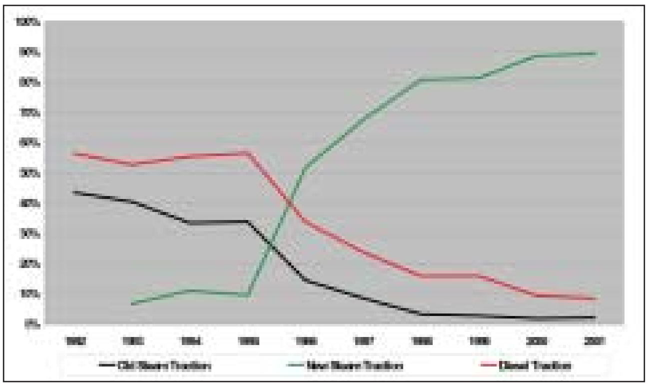


Fig. 18: Schafberg Railway: Modal split between old steam traction, diesel traction and modern steam traction from 1992 to 2001. The percentages relate to actual mileages times the seat capacity.

The diesel railcars are still there, but are being used less and less. Before the new steam locomotives arrived, the diesel railcars carried some 55 % of the passengers, but this was down to about 8 % in 2001. The old coal-fired steam locomotives transported some 3 % only. This may be explained by the much longer journey time and the "nostalgia"- supplementary fare. According to observations of the railway staff, the average passengers, whilst exactly discriminating between diesel and steam traction, do not differentiate between old and new steam trains.

The rolling stock of the Schafberg Railway now consists of:

Rolling Stock of the Schafberg Railway as from 1996							
Engine No.	Type	Built	Coaches	Seats	Train Crew	Productivity	Speed
999.102…106	Steam	1893	1	60	3	100 %	7 km/h
5099.001, 002	Diesel	1965	Railcar	77	2	192.5 %	12 km/h
999.201	Steam	1992	2	110	2	275 %	12 km/h
999.202 - 204	Steam	1996	2	105	2	262.5 %	12 km/h

Table 4: Rolling Stock of the Schafberg Railway as from 1996. Productivity relates to the number of passengers per train crew member in relation to the oldest steam train. The seating capacity of the diesel railcars has been reduced to 70 passengers as from 2001 for reason of fire safety.

Fig. 19: No rule without exception. Modern steam train of the Schafberg Railway in winter operation

While the modern steam locomotives carry the major part of the traffic on both the Brienz-Rothorn and the Schafberg Railway, locomotive No. 1 of the Montreux–Glion – Rochers-de-Naye has the task of increasing the attractions of this otherwise electric railway. Ancient wooden “Belle Époque” coaches are being used, which look very good, but are not of lightweight construction. As this steam train is in contrast to the electric railcars, a “steam”- supplementary fare is charged. Due to the different operating concept and the restriction marked in the timetable (“in fine weather only”), the locomotive No. 1 does only about half the mileage the other new steam locomotives do. The entire steam operation on this railway relies on the one locomotive, there is no spare locomotive and hardly any spare parts!

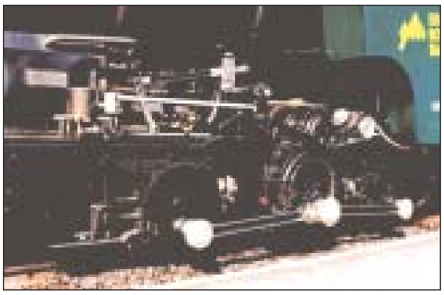


Fig. 20: The drive mechanism of the new steam locomotives is of modern technology, but none the less attractive to watch.

10. REBUILDS AND MODERNISATIONS

The following locomotives have been rebuilt using *modern steam* technology:

- 0-4-0 900 mm gauge tank locomotive, Borkumer Kleinbahn
- 2-10-0 Standard gauge locomotive 52 8055, Eisenbahnfreunde Zollernbahn e.V.
- HG 2/3 Rack and adhesion metre gauge locomotive, Brig-Visp-Zermatt Railway

All have been converted to light oil firing. The most comprehensive modernisation was done to 52 8055, which proved that *modern steam* technology is not limited to rack locomotives. A new light oil firing system, ten times more powerful, had to be developed and this created quite a few headaches, especially in view of undesired noise and vibrations. In the end we succeeded, but with hindsight, an entirely new design of the locomotive would have made life much easier.

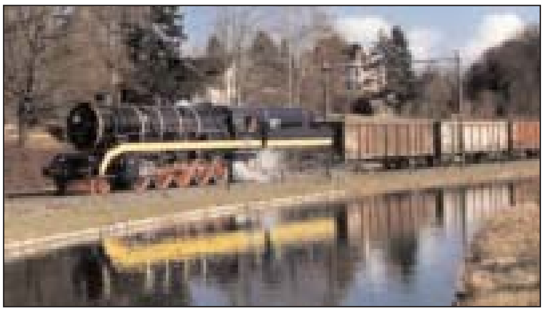


Fig. 21: Modernised 52 8055 with a test train. With the new lightweight drive, equipped with roller bearings throughout, 41 % of the reciprocating masses were balanced compared to 15 % on the original design. The result was a very smooth ride even at maximum speed, whilst the original 52 class locomotives were notorious for their rough riding behaviour.

Fig. 22: Modernised oil-fired 52 8055 leads un-rebuilt coal-fired 52 7596 on the Orient Express. Each time a coal fired locomotive was used, the entire train had to be cleaned from soot and coal particles. Using 52 8055 saved a lot of man-hours of train cleaning alone.

It must be stressed that modernisation does not generally give the same excellent results that can be achieved with entirely new designs. The old components usually severely limit the scope for engineering re-design. As a consequence, the economic and technical results are usually much closer to those of the old design than to those that could be achieved with an all new locomotive.

11. NEW STEAM ENGINES FOR PADDLE SHIPS

Between 1933 and 1977 the Swiss Compagnie Générale de Navigation sur le Lac Léman (CGN), which operates passenger ships on Lake Geneva, converted six paddle steamers to diesel-electric drive in order to save on operating costs. Four were still in service in 1996. By that time, because diesel and electric units have a generally shorter life expectancy than steam engines, the time to replace the propulsion units was clearly close at hand. It seemed quite clear at first that new diesel-electric drives would be installed, but a new concept of the author to control a steam engine from the bridge by means of a remote control in combination with automatic boiler controls would enable steamships to run with the same number of staff as diesel ships of equivalent size. In this way the previously biggest economic disadvantage of the traditional steamer could be eliminated.

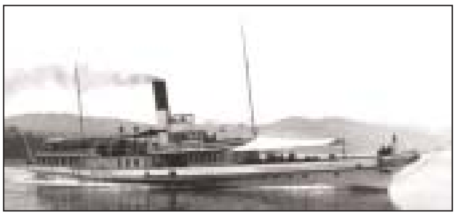


Fig.23: The "Montreux" was built in 1907 as a coal fired paddle steamer by the well-known Swiss company Sulzer Ltd.

Fig. 24: The "Montreux" after conversion to diesel-electric drive, which improved the economics but certainly not the aesthetics.

Fig. 25: Equipped with a new economic steam engine remote-controlled from the bridge, the entirely refurbished "Montreux" delights passengers, onlookers and accountants.

The paddle steamer re-entered commercial service on 19th May 2000, when it was leading the parade of the four other traditional paddle steamers.

The new steam engine for the "Montreux" had been ordered at the end of 1997, following a feasibility study. It was the first ship steam engine to be built in Switzerland since 1928! As with to the modern rack steam locomotives, the ship steam engine was tested and instrumented extensively before delivery (figure 26).

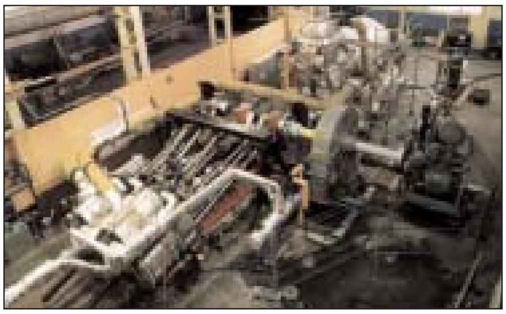


Fig. 26: Test stand with boiler, main steam pipe and steam engine exactly positioned as on the ship. The gear is from the obsolete diesel-electric drive and used here to increase the speed of the water brake.

The two-cylinder steam engine produces a continuous indicated power of 710 kW at 50 revs/min. With a bore of 560mm and a stroke of 1200 mm, the engine is rather impressive. Joy-valve gear has been chosen so that a 1000 kW three-cylinder version can be built without the need of a complete new design.

Fig. 27: Smooth and silent running even at full speed and power are synonymous with steam engines on paddle ships. This allows an open engine room, increasing the attractiveness to the passengers. An open engine room would be quite impossible on diesel ships where the best in acoustic insulation is needed to make it acceptable for the passengers.

With a reliability of 100 % since then, the steam engine installation has done very well indeed.

12. PROJECTS

12.1 Steam Locomotives for Tourist Trains

This paper is the first to publish the convincing economic results of the modern rack steam locomotives. The fact that the operating costs of *modern steam* power are not higher than the operating costs of diesel traction is largely unknown. It is therefore not surprising that most railway managers are still convinced that steam traction can only be considered for tourist trains. As long as this view prevails, justified or not, it makes sense to primarily search the market for projects linked with tourism.

The following details are from a selection of locomotive projects, most of them based on initial requests by a railway.

<u>Narrow Gauge Steam Locomotives for India</u>

The well-known 2 foot (610 mm) gauge Darjeeling is a spectacular line incorporating several loops and switch-back sections. As one of only two railways, the Darjeeling Railway has been declared a World Heritage Site by the UNESCO. The railway used to be operated exclusively by "B"-class locomotives, the design of which dates back to the 1880's. A crew of five is used on these small locomotives, quite a lot even by Indian standards! Diesel locomotives have been introduced recently, following the clean sweep policy of Indian Railways to eliminate steam. Nowadays there is more steam operation in tiny Switzerland than in giant India! The few operable Darjeeling steam locomotives have mainly been relegated to a new short-distance tourist train. Train operation on the Darjeeling railway is only a shadow of its former self and one can only wonder why UNESCO tolerates this.

However, in an attempt to keep some steam traction on this famous line, global tenders had been issued for three new oil fired steam locomotives. DLM presented an offer for an all-new design incorporating the latest *modern steam* technology with the external appearance closely resembling the old "B"-class locomotives. These locomotives would outperform the diesel locomotives by hauling five instead of four coaches at a higher uphill speed.

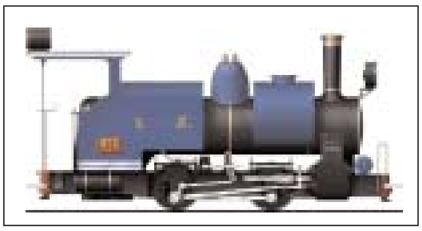


Fig. 28: New oil fired steam locomotive as proposed to the Indian Railways for the Darjeeling line. The distinct external appearance, which is characteristic for the Darjeeling Railway was intentionally retained in view of the UNESCO World Heritage status.

<u>Tank Locomotive for European Narrow Gauge Lines</u>

Back in 1990, the then DR (Deutsche Reichsbahn) heard of SLM's intention to build new rack steam locomotives and showed interest to buy no less than 30 new steam locomotives

(10 for metre gauge, 20 for 750mm gauge). Following this request, a modern 2-10-2 tank locomotive was initially proposed, incorporating all the features of the *modern steam* technology, but later SLM pulled out: the rack tank locomotives were not yet built and the order books were full.

Both SLM and DR exist no more, but the steam operated narrow gauge lines have survived. Most lines are now privatised, but two lines near Dresden remain with DB. The infrequent service and a maximum speed of 30 km/h on 750 mm gauge and 40 km/h on the metre gauge make these lines unsuitable for commuters. This was different in the days of communism when there was simply no alternative. Today commuters go by car or bus, and many lines in the former East Germany have been closed for lack of passengers. Not so the steam operated railways, where the tourists are more than happy to fill the trains. Even though the trains are mostly used by tourists nowadays, these lines are not typical tourist railways, offering a daily time-tabled service.

Whilst most of these lines have recognised the value of steam traction, DB is still unconcerned. As DB is now running trains as a subcontractor to the Verkehrsverbund Oberelbe, being paid by kilometres run, they have little interest in ticket revenue. DB's interest is to lower operating costs, for which the standard answer nowadays is diesel railcars. But who will use them on these lines? Modern steam locomotives provide a much better solution in terms of attractiveness, transport capacity and operating costs per seat. Since the track has been upgraded on all lines, DLM is offering a 2-8-2 with an axle load of 12.5 tons instead of the 2-10-2 with an axle load of 10 tons. Whilst the same tractive effort is retained, the maximum speed can be raised to 70 km/h, equal to the speed the railcars would achieve.

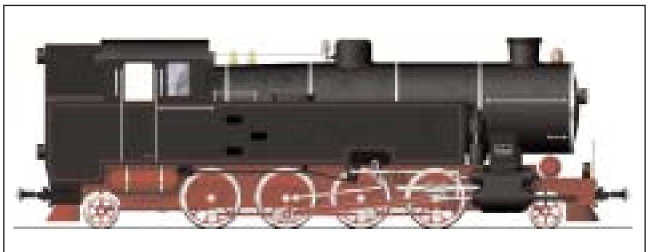


Fig. 30: DLM proposal for a narrow gauge 2-8-2 destined mainly for the steam operated lines in the eastern part of Germany.

The problem is that the diesel railcars would be subsidised by 90 %, whereas the modern steam locomotives are not, which is unfair competition. The "logic" behind this argument is that suburban traffic is losing money and therefore has to be subsidised, whereas steam locomotives are used in tourism, which is expected to make a profit! Some of the railways now try to convince the Government to equally subsidise the modern steam locomotives, realising it's the best solution for them.

<u>Tank Locomotive for European Standard Gauge Lines</u>

When a local committee took the initiative to re-activate the scenic standard gauge line from Merano to Malles in northern Italy, they proposed to use modern steam locomotives in combination with modern panoramic coaches, resembling the ones that had been built for Swiss narrow gauge railways. The artist's impression shows how well the new steam locomotive would match the coaches. Push-pull operation was also suggested whereby the locomotive would have been remote-controlled from the driving trailer car. But in 1997 the time was not ripe for such unconventional ideas. Later on diesel railcars were ordered, proving that it takes a long time to change a paradigm.

Fig. 31: Artist's impression of a modern standard gauge steam train. Drawing by H.R. Kaegi

More projects can be found on the DLM-Homepage: www.dlm.ag or www.dlm-ag.ch

12.2 Steam Locomotives for Industrial Use

Diesel locomotives nowadays have a virtual monopoly on shunting duties. Technically this is a bit difficult to understand, as the diesel engine has some shortcomings, which do not make it an ideal shunting locomotive. As the diesel engine alone cannot start under load, an electric or hydraulic transmission is necessary, making it a rather complicated and expensive locomotive. In service the diesel engine idles for most of the time, doing no useful work but polluting the environment with toxic and carcinogenic exhaust gases, noise and vibrations. Measurements show that diesel locomotives on shunting duties run at idling speed 75 % of the time. When the author checked the mileage and the operating hour meters of several shunting locomotives, the average speed turned out to be between 1.5 and 4.5 km/h! Because there is no energy storage, the diesel engine has to follow load in shunting duty frequent changes of the traction, thereby producing emissions of very bad quality.

Modern steam technology, employing old refurbished as well as new ideas, could provide a much more environmental-friendly shunting locomotive. For part of the trip, for instance in tunnels, completely emission-free operation could be guaranteed.

13. SUMMARY AND PROSPECTS

Eleven years of experience show that the new rack steam locomotives have acquitted themselves very well. The requirements laid down in the specification have been met or exceeded. Compared with other prototype motive power the commissioning time was extremely short, enabling the locomotives to assume commercial operation soon after delivery.

Most of the shortcomings of traditional steam traction have been eliminated on these modern locomotives. In operational readiness, availability and personnel costs they can match diesel and electric traction. Fuel costs now amount to a very low percentage of the operational costs. The comparison of operating costs on the Brienz-Rothorn Railway shows that they are five to ten times lower than those of old steam power, but more important, equal to those of diesel traction under the same conditions. Environmental nuisance is no longer a problem with the new oil fired steam locomotives. It has been demonstrated in practice that the CO- and NOx-emissions are even less than those from comparable diesel locomotives equipped with the latest engines.

The fact that the operating costs of new steam locomotives are not higher than those of good diesel locomotives opens up a new field of applications. Whereas the use of modern steam locomotives has been justified by the needs of tourism, *modern steam* locomotives can now be considered for other traction purposes as well. The author is well aware of the fact that this kind of lateral thinking will take more time until the majority of railways start to consider evaluating *modern steam* traction. But the economic results of *modern steam* in both rail traction and marine applications justify a fresh and wholly unbiased review of the merits of steam traction, not only for tourism. By the way, who said that only tourists like to ride clean steam trains? Decisions are not only based on rational arguments such as travel time, frequency of service and ticket price, otherwise less people would use cars. Emotions are a factor we engineers tend to overlook, but emotions are a fact of life and when it comes to the emotion factor, steam is top. The railways could take advantage of this again.

It has to be emphasised that the convincing results with the new rack steam locomotives were achieved with a very small fraction of the development money spent for the development of diesel and electric locomotives. This in turn means that the development of the steam locomotive is far from having reached its peak. Even if the classical reciprocating drive is retained, which is essential for tourist trains, there is still a lot of potential for improvements. For normal traction purposes not linked with tourism, other forms of steam power (i.e. steam-electric) could be considered, but it must be borne in mind that the more one deviates from the principles of the classical steam locomotive, the more development work is needed and the higher the technical and financial risks may be.

This author is not going to predict the future. However the future of railways might just be a little brighter if all traction options were considered. Nowadays economic calculations can be done easily. One has to considered that comparative conditions are not only different in each country but also for each line. To find the economic optimum for each line, all three forms of motive power will have to be considered again: diesel, electric and ***modern steam***.

Acknowledgements

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