Tooth by tooth. Part 2, Steam power on the rack

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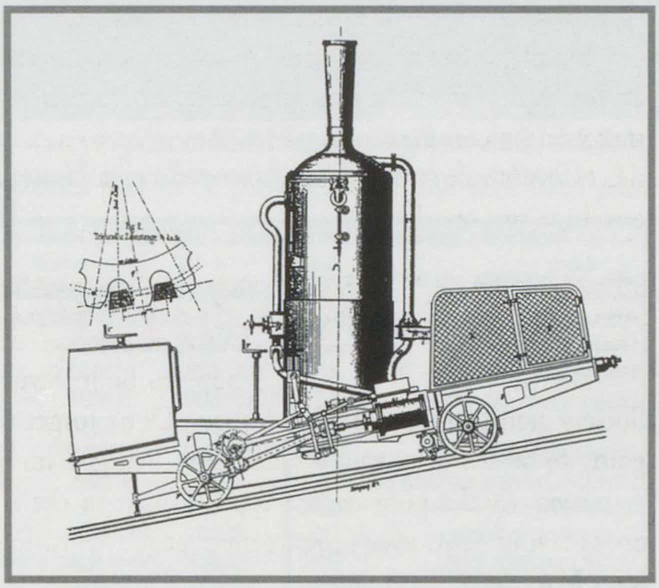
TOOTH BY TOOTH
Part 2 - Steam power on the Rack

4. General information on steam driven rack locomotives.

Except for the drive mechanisms, rack steam locomotives are representatives of the classic Stephenson steam engine. However there is one important point which should be borne in mind. The tractive and braking forces of locomotives for rack operation only are transmitted by the cog wheels, the wheels in contact with the rails have a carrying function only and in most cases run loose. On steam locomotives for mixed operation with separate drive mechanisms for adhesion and rack working, the rack drive still contributes a much higher percentage of the tractive force than the adhesion engine. Members who wish to check the performances of the locomotives for which I am giving technical data should consider three important points. First: the steam consumption in kg per HP hour is in some cases 15-25 % higher than that of comparable narrow gauge adhesion engines due to the lower cylinder volumes. Second: due to the additional friction produced between rack bar and rack wheel we have to account for a further loss of tractive force varying between 6 - 9 %, depending on the type and condition of the rack bar. Third: the falling atmospheric pressure when operating in altitudes from 1100 - 2000 meters causes a higher counter pressure in the blastpipe leading to a still higher steam consumption. Contrary to what has been put forward by some German experts, all rack engine builders knew the reason for this phenomenon, but a scientific analysis could not be made due to the lack of precise measuring instruments. During the thirties the work done by Chapelon, Altmann and later Giesl-Gieslingen led to a satisfactory solution of the problem culminating in the Giesl ejector reducing the steam and coal consumption significantly, in some cases by 33 %. But by that time electrification was almost completed in Switzerland and elsewhere or the owner of rack operated lines had changed to diesel operation or had removed the rack bars in favour of very powerful steam locomotives with axle loads of 20 tonnes and more.

It is not possible to discuss each engine built, so I shall deal with the most important groups only.



4.1.1 Riggenbach's first rack loco for the Vitznau-Rigi Railway.
Courtesy: SULZER/SLM Riggenbach collection

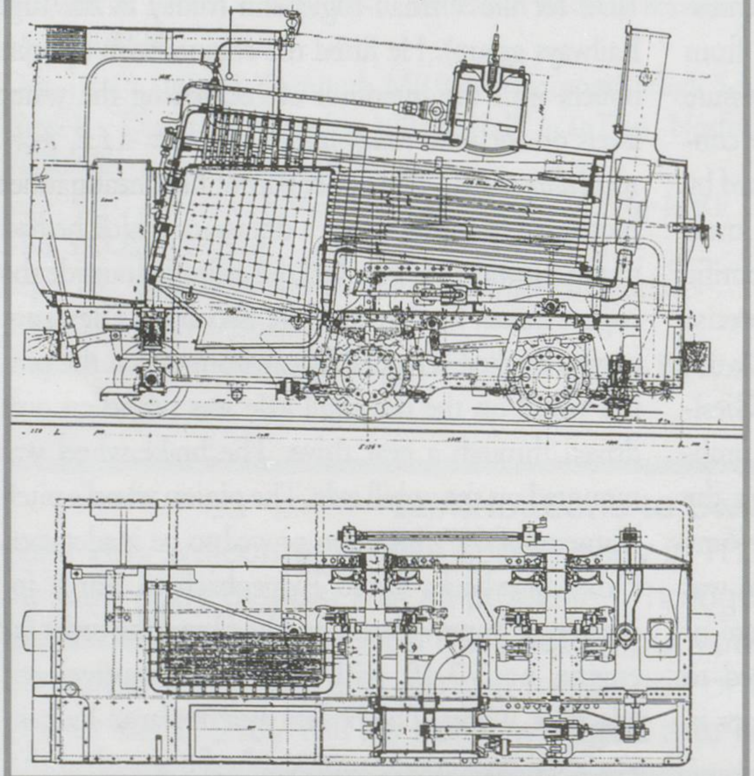
4.1. Steam locos for end to end rack operation.

Nicolas Riggenbach built and supplied the first 6 standard gauge rack locomotives between 1870-1872 for the Vitznau-Rigi-Bahn (today in the Rigi Railways group). He fitted the engines with upright boilers with the intention of controlling the water levels on inclines. *(diagram 4.1.1, photo 4.1.2, technical data 4.1.3).* The upper part of the heating tubes protruded from the water, a drawback which he had to put up with. He installed the cylinders outside the engine frame, but between the two axles. The steam engine worked on a crankshaft from which the pinion wheel on the downhill axle was propelled over driven through a gear drive. The brake wheel was mounted on the uphill axle. The pinion wheel's pitch diameter of 637 mm soon proved to be inadequate. Other drawbacks forced Riggenbach to search for important improvements and he placed the order for engine nos. 7-10 with Swiss Locomotive and Machine Works. The boilers were replaced by conventional ones tilting towards the front end so that

4.1.2 - Vitznau-Rigi train ca.1872.
Courtesy Sulzer/SLM archives-collection Hauser

4.1.3 -Technical Data Steam Locomotives - Vitznau-Rigi Railway				
Numbers	1-3	4-10	1-10 rebuilt	11/12
Constructed	1871/1872	1872/1873	1882/1892	1899/1902
Axle config.	0-2-0	0-2-0	0-2-0	0-2-0
Overall length (mm)	6200	6200	6200	6500
Cog wheel dia.(mm)	637	637	637	891
Brake wheel dia. (mm)	637	637	637	637
Running wheel dia. (mm)	660	660	660	660
Drive gear ratio	1:3.07	1:3.07	1:3.07	1:3.03
Effective heating surface (m^2)	39,54	58.4	48	53.1
Grate area (m^2)	0,90	0.9	1	0.93
Superheating surface	0	0	0	15.4
Boiler pressure (bar)	9,80	9.8	9.8	11.76
Cylinder dia. (mm)	270	270	270	290
Stroke (mm)	400	400	400	450
Starting tractive force (kN)	ca. 53	53	53	53
Max. speed (km/h)	7.5	7.5	7.5	9
Weight-loco (tonnes)	12.50	15.1	18	19.4
cars	7.50	7.5	7.5	7.8
train	20	22.6	25.5	27.2
Pwr. output (kWh app)	88.00	100	113	160

4.1.5 - Snowdon Mountain Railway rack locomotive
Courtesy: SLM. Hauser collection

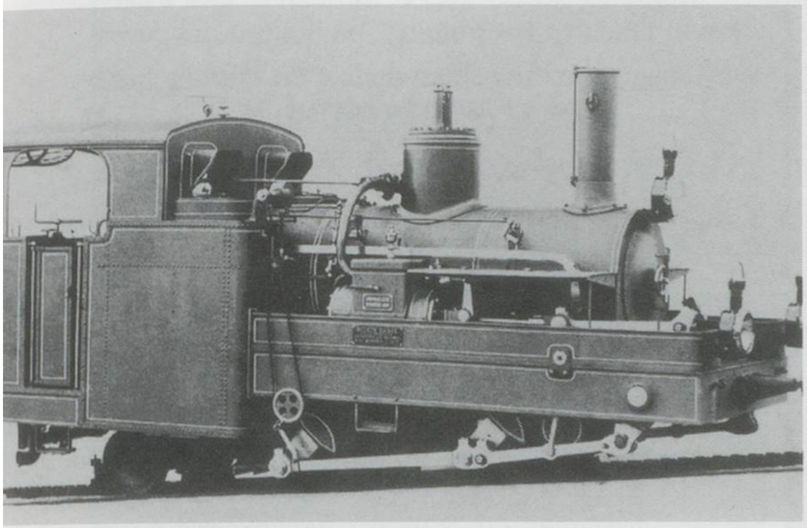


they were level on gradients. In addition speedometers were installed as well as an automatic steam brake which was applied when the set speed was exceeded, in addition to the existing Riggenbach counter pressure brake. The latter became standard for steam operated rack engines, therefore it may be useful to explain it briefly. In a reversal of their function the cylinders work as air pumps with a throttled exhaust. To achieve this Riggenbach installed a rotary valve in the exhaust pipe connecting the cylinders with the open air instead of the smoke box in order to suck clean air. The throttle is closed but the space between throttle and slide valve case is connected with the open air through a cock. During the piston's forward stroke air is taken in from the blastpipe and is compressed during the the reversal of the piston. With the cock mentioned above, the driver regulates the exhaust of air and therefore the braking force. To prevent an overheating of the cylinders due to the air compression, the driver introduces small amounts of cold water which exhausts as steam when the brake is working.

Riggenbach decided to modify the above basic design for the engines of the Arth-Rigi railway by placing the pinion wheel on its own axle installed in the locomotive frame. It was now possible to use cog wheels up to 1050 mm diameter with a higher number of teeth leading to lower wearing of the pinion wheel.

A different engine design was required for the many 800 and 1000 mm gauge lines built in rapid succession during 1889-1895. Here the available space between the locomotive frames was barely sufficient to place the pinion wheels and the brake discs. The axle bearings and the frames had therefore to be placed outside the running wheels, whereas the cylinders were mounted on the frame beside the boiler, driving oscillating levers which in their turn worked on two pinion wheels pressed on the axles in the locomotive frames. The beauty of this solution was the possibility of determining the exact piston stroke by choosing the correct lever length. Furthermore the cylinder bore

4.1.6. Wengernalp loco with oscillating levers.
Courtesy Sulzer/SLM archives-collection Hauser

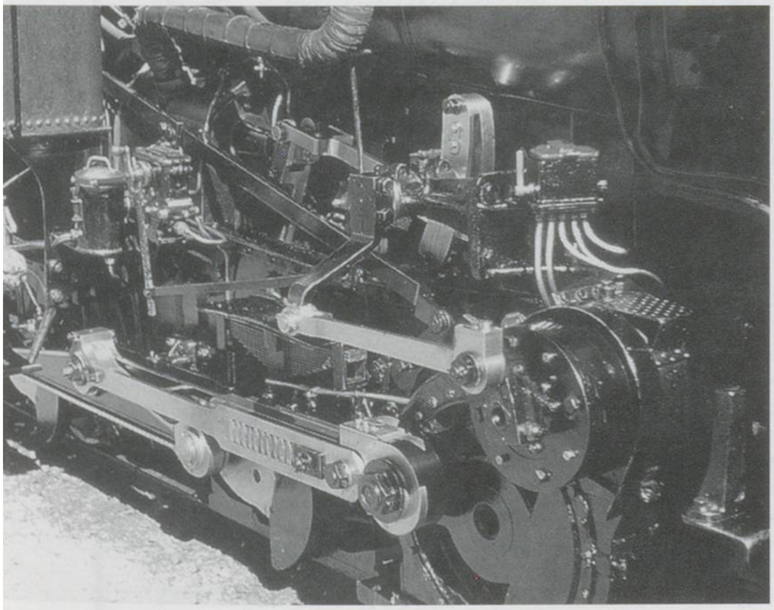


could be kept small and the moving masses low. However the builders had to use a pinion wheel diameter of 573 mm again due to the restricted space. This engine type became standard for many years on narrow gauge tourist lines, such as the Wengernalp, the Brienz-Rothorn, the Glion-Rochers de Naye and others in foreign countries outside Switzerland. The gear ratios varied from 1: 1.3 - 1: 2.5. As already pointed out the running wheels, mounted loose on the axles had solely a carrying function. Hence, all tracks even the level ones had to be provided with the rack bar.*(plan 4.1.5 Snowdon Mountain Railway, photo 4.1.6 of Wengernalp engine, and technical data 4.1.8).*

4.1.8 - Steam Locomotives of the Snowdon Mountain and the Wengernalpbahn Railways

	Snowdon	Snowdon	WAB	WAB	WAB	WAB
Numbers	1-5	6-8	1-8	9-12	13/14	31/32
Built in	1895	1922/1923	1893	1895/1896	1898	1904/1906
Axle config.	0-2-1	0-2-1	0-2-1	0-2-1	0-2-1	0-2-1
Overall length mm	5176	5926	5550	5126	5126	6670
Cog wheel dia mm	573	573	573	573	573	573
Brake wheel dia mm						
Running wheel dia mm	653/520	656/522	653/520	653/520	653/520	520
Drive	oscill.levers	oscill.levers	oscill.levers	oscill.levers	oscill.levers	gear
Gear ratio	1:1.40	1:1.515	1:1.4	1:1.4	1:1.50	1:2.67
Effective heating surface m2	36.9	29.5	33.75	36.8	36.3	53.8
Grate area m2	0.95	0.78	0.66	0.8	0.8	0.9
Superheating surface		7.7				
Boiler pressure bar	13.73	13.73	13.73	13.73	13.73	11.76
Cylinder dia mm	300	300	300	300	300	360
Stroke mm	600	600	550	600	600	400
Starting tractive force kN	69	78.5	56	73 5	73.5	110
Max. speed km/h	8	8	9	9	9	9
Weight tonnes - loco	17.55	20	17	17	16.6	19.3
- cars	18.30	19	8.75	8.75	8.75	13.7
Total train weight	35.85	39	25.75	25.75	25.35	33
Approx. power output kW	155.00	170	170	170	170	220
Builder	SLM	SLM	SLM	SLM	SLM	SLM

The next step was the design of locomotives with a higher power output, being able to push 2 passenger coaches on the ascent instead of only one. Both the Brienz-Rothorn-Bahn and the Vitznau Rigi line took put into service 5 locomotives in all with a pushing force of 8 and 14 tonnes respectively. These engines were fitted with the Schmidt system super heaters right from the start *(See photo 4.1.9 and technical data 4.1.10).*

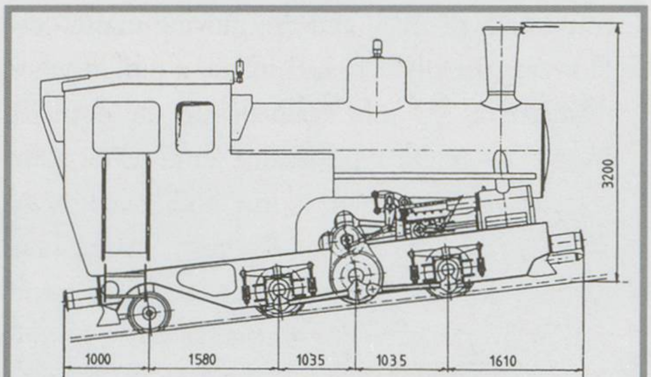


4.1.9 - Brienz Rothorn loco no.8 shows off its drive mechanism. July 1998. Photo: Hauser-Gubser

4.1.10 - Steam loco nos. 6 /7 of the Brienz-Rothorn-Railway

Numbers	6/7
Built in	1933
Axle config.	0-2-1
Overall length (mm)	6410
Cog wheel dia (mm)	573
Brake wheel dia (mm)	
Running wheel dia (mm)	653/520
Drive	gear
Gear ratio	1:2.2
Effective heating surface (m^2)	30
Grate area (m^2)	0.76
Superheating surface	6.45
Boiler pressure (bar)	13.73
Cylinder dia (mm)	300
Stroke (mm)	400
Starting tractive force (kN)	78.5
Max. speed (km/h)	8
Weight tonnes - loco	18.83
cars	11.17
Total weight train	30
Approx. power output (kW)	180
Builder	SLM

With the advent of electric traction on tourist lines, the need for steam locomotives began to evaporate. During the 1980s however, the managements of the BRB and the Montreux-Glion-Rochers de Naye



4.1.11 - Outline drawing of the latest steam engine for the BRB. *Courtesy SLM*

4.1.12 - BRB no.15 built by SLM in 1996 and photographed at Brienz 18/6/1996 by Nick Freezer

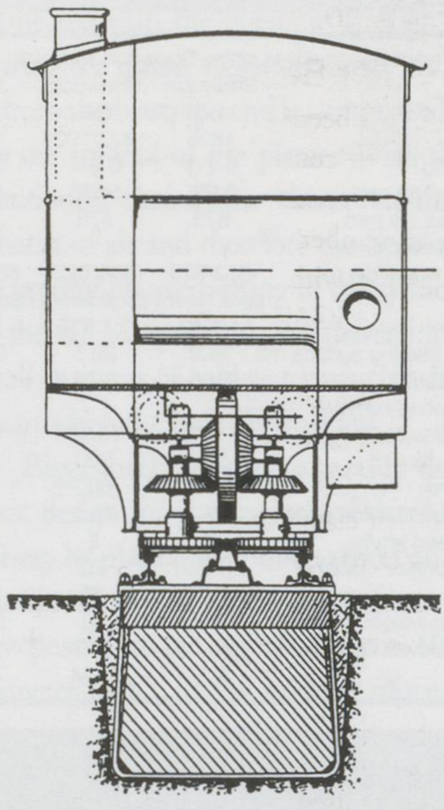
4.1.13 - Modern Steam locomotives of the Brienz-Rothorn-Railway

Number built	3
Built in	1992/6
Axle config.	0-2-1
Overall length (mm)	6260
Cog wheel dia (mm)	573
Brake wheel dia (mm)	
Running wheel dia (mm)	649/440
Drive	gear
Gear ratio	1:2.3
Effective heating surface (m^2)	36
Grate area (m^2)	0.8
Superheating surface	14.4
Boiler pressure (bar)	16.7
Cylinder dia (mm)	280
Stroke (mm)	400
Starting tractive force (kN)	140
Max. speed (km/h)	12
Weight tonnes - loco	15
cars	25
Total weight train	40
Approx. power output (kW)	350
Builder	SLM

became aware of the nostalgia for steam among a sizable part of their customers. Together with the Austrian Federal Railways new locomotives were ordered from SLM similar in appearance to the classic engine, but fitted with modern devices. The engines are oil fired and equipped with sophisticated safety equipment so that no fireman is needed. Wholly welded, the weight was reduced in favour of the payload by 2 tonnes against the engines of the thirties. There are roller bearings and a central automatic lubrication system. Efficient insulation in combination with electric preheating reduces preparation time to a few minutes. Working at full power the engines produce about double the pushing force yet using 25 % of the water and 50 % of the fuel when compared to the old engines working with saturated steam. *(diagram 4.1.11, photos 4.1.12, technical data 4.1.13)*

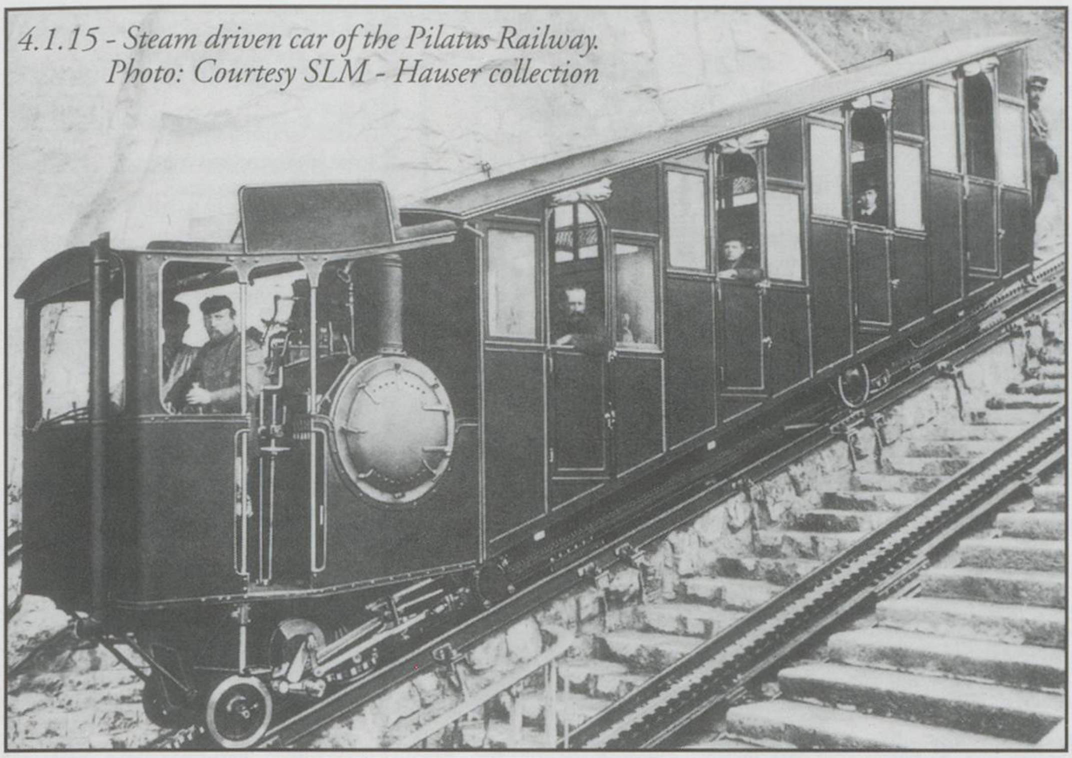
The steam cars built by SLM for the Pilatus railway are a unique example of rack railway engineer-

4.1.14 - Pilatus Railway steam car showing unique drive system. *Courtesy Sulzer/SLM archives*



4.1.16 - Steam Railcars of the Pilatus Railway

Numbers	1-3	4-6	7-10	11
Built in	1886/1887	1888	1899/1900	1909
Axle config.	Bhd 1/2	Bhd 1/2	Bhd 1/2	Bhd 1/2
Overall length (mm)	9700	10300	10300	10850
Cog wheel dia (mm)	2/405	2/405	2/405	2/405
Brake wheel dia (mm)	2/405	2/405	2/405	2/405
Running wheel dia. (mm)	400	400	400	400
Drive	all cars direct gear reduction			
Gear ratio	1:3.628	1:3.628	1:3.628	1:3.628
Effective heating surface (m^2)	19.3	21	19.8	16.5
Grate area (m^2)	0.38	0.38	0.38	0.38
Superheating surface				3.3
Boiler pressure (bar)	11.75	11.75	11.75	11.75
Cylinder dia (mm)	220	220	220	235
Stroke (mm)	300	300	300	300
Starting tractive force (kN)	54	54	54	54
Max. speed (km/h)	6	6	6	7
Total weight: train	13	1 18	12 4	13.3
Approx. power output (kW)	100	98	90	125
Builder	SLM	SLM	SLM	SLM/SIG



4.1.15 - Steam driven car of the Pilatus Railway. Photo: Courtesy SLM - Hauser collection

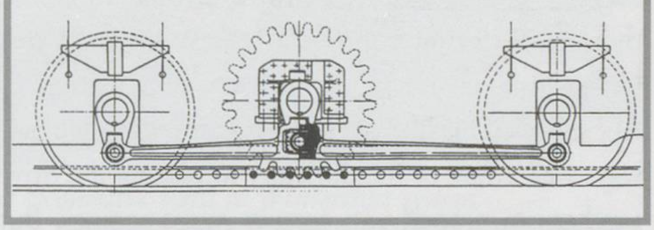
ing. 11 were supplied in 1887, a further 3 in 1888/9 and one each in 1900 and 1909. Designed as two axle vehicles, the downhill axle carried the machinery (boiler, drive mechanism, cab etc), whereas the passenger compartment was borne by the uphill axle. The seats of the latter are arranged in steps to compensate for the steep incline. The drive is shown in drawing 4.1.14. *(see also photo 4.1.15 and technical data 4.1.16).*

4.2. Steam locomotives for mixed adhesion/rack operations.

Whilst rack locomotives for permanent rack operations are generally used by tourist lines or on industrial sites, engines for mixed rack and adhesion service have to work on comparatively long sections, handling passenger and freight traffic both in transit as well as that generated locally. The overall average speed needed to be considerably higher than that on a tourist line. A rule of thumb is that not more than about 30-40% of the whole line length should be fitted with a rack bar in order to achieve high average speeds. It is also very useful if the inclines of the adhesion sections are, if possible, below 40 % (1 in 25) in order to profit from relatively high loads.

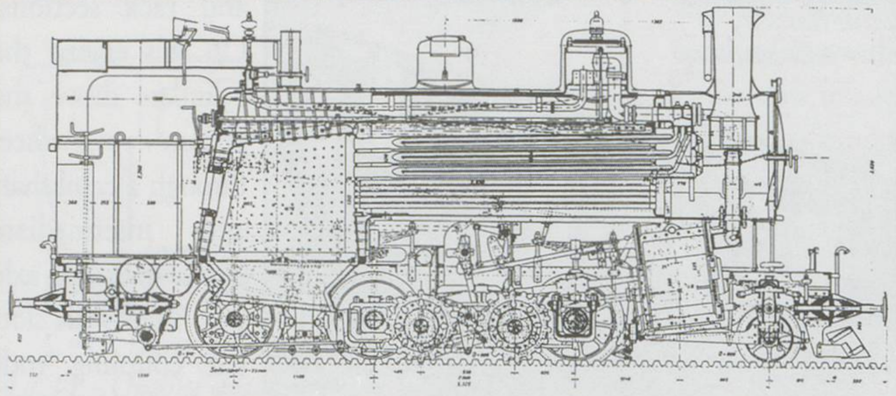
Before the Brünig line started operation in 1888, SLM was asked to supply a steam engine able to operate with the same drive mechanism on adhesion and rack sections. On this engine the cylinders drove the pinion wheel through a crankshaft and intermediate gear wheels. Its axle was fitted with slotted coupling rods driving, in their turn, the adhesion wheel axles *(refer to sketch 4.2.1)*, i.e the adhesion wheels were coupled permanently to the rack drive. In theory the adhesion wheel diameters should be the same as the pitch

4.2.1 - Brünig locomotive drive mechanism for combined rack/adhesion operation. Diagram: Courtesy SLM



diameter of the pinion wheel. But the wear of the latter is lower than that of the former, which is in permanent contact with the rails, therefore these have to be mounted with a somewhat larger diameter when new, to compensate for subsequent use. Evidently new wheels have a higher circumferential speed than the cog wheel, whereas used wheels have a tendency to begin to slip when the difference in diameter is too high, producing an additional strain on the drive mechanism. The gear ratio was 1:1.8. Therefore the piston speeds were comparable to those of the engines for the Wengernalpbahn, so small cylinders were possible. At the same time the masses in motion were significantly reduced .

Soon the 13 tiny engines, overworked by the rapidly increasing traffic, began to show serious signs of wear. The management opted for a more advanced solution. The idea of separated drives for both kinds



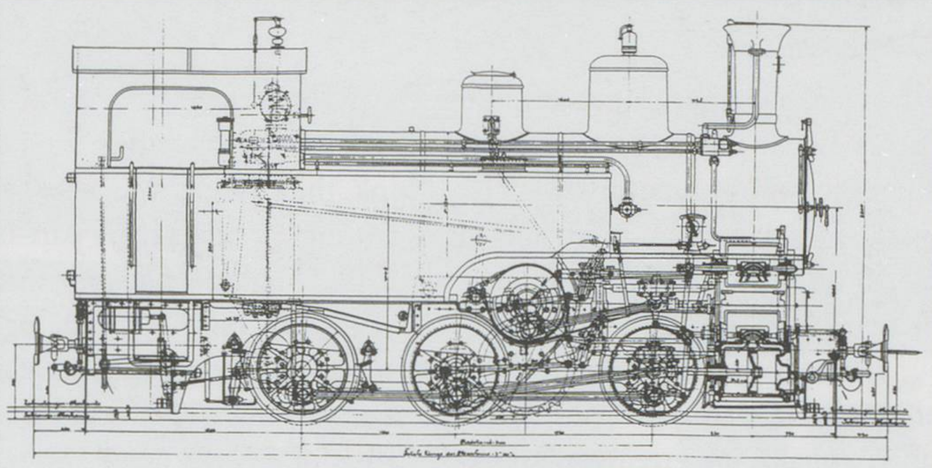
4.2.3 - Furka Oberalp dual drive loco. Diagram: Courtesy SLM

4.2.5 - Steam locomotives of the Furka Oberalp Railway	
Number built	10
Built in	1913/14
Overall length (mm)	8754
Total wheelbase (mm)	5325
Rigid wheelbase (mm)	2000
Pilot wheel dia. (mm)	600
Adhn driving wheel dia. (mm)	910
Cog wheel dia. (mm)	688
No. of cog wheels	2
Drive	Abt 4 cyl.
Gear rdn-(adhesion drive)	1:1
-(rack drive)	1:1
Effective heating surface (m^2)	66.6
Grate area (m^2)	1.4
Superheating surface (m^2)	17.2
Boiler pressure (bar)	13.73
Cyl. dia.-high pressure (mm)	280
Stroke-high pressure (mm)	400
Cyl. dia.-low pressure (mm)	280
Stroke-low pressure (mm)	400
Starting tractive force (kN)	127.5
Max. speed (km/h)- adhn.	45
Max. speed (km/h)- rack	20
Weight tonnes - loco	42
load	60
Total weight train	102
Approx. power output (kW)	416
Builder	SLM

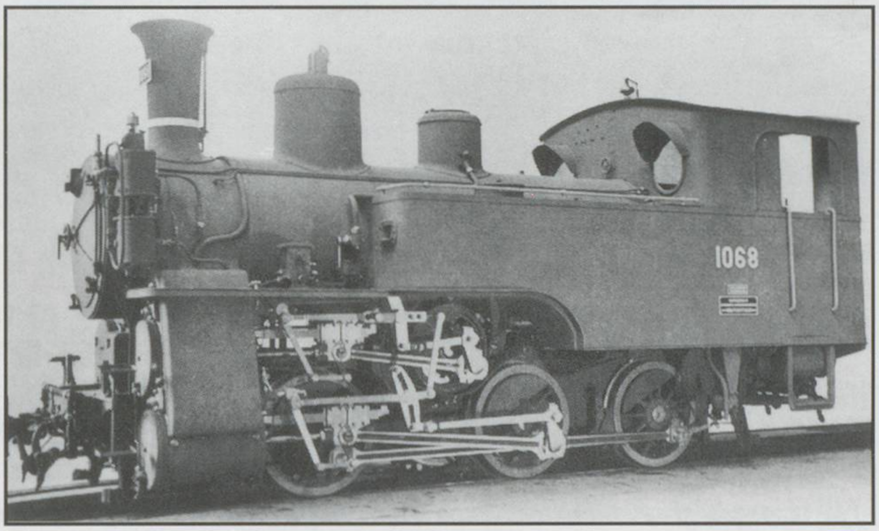
of operation had been in the air for some time already when, Roman Abt, the inventor of the Abt lamella rack bar, came forward with his idea of a four cylinder engine. All cylinders were working more or less on one level. The outside ones were used on adhesion sections whilst the inner cylinders drove the cog wheels supported by an auxiliary frame installed between the first and second axle. All 4 cylinders were working on rack sections with full boiler pressure. Compound working was rare. The steam engines were operated by two regulators. To obtain the correct distribution of the tractive force on rack sections, the cylinders had different bore diameters. Abt supplied his first engines for standard gauge railways well aware of the difficulty in placing the drive mechanism properly on narrow gauge engines. But by 1890 he succeeded in mounting his drive into meter gauge locomotives delivered to the Visp-Zermatt railway. The most powerful engines constructed to the Abt system for a Swiss narrow gauge line were supplied to the Furka-Oberalp Railway with a power output of about 440 kW (ca. 600 HP). They were one of the rare examples of a compound working engine. *(see drawings 4.2.3, photo 4.2.4, technical data 4.2.5).* Some 300 similarly conceived engines of various axle configurations, power and tractive force were produced by several European builders. Roman Abt also introduced the sprung pinion wheel leading to smoother riding on rack sections. The separate drive mechanisms were a breakthrough in rack railway technology. This was especially true for countries in the Far East or South America where it was difficult to obtain the capital required to build extensive adhesion lines.

4.2.4 - Furka Oberalp no. 10 at Gletsch 19/8/1954
Photo: Hauser-Gubser

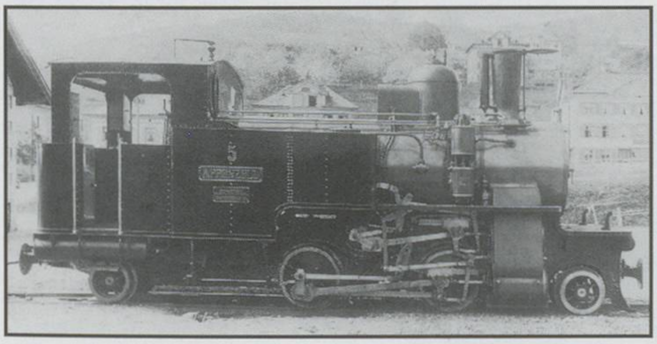
For the Brünig line however, SLM's head of locomotive design, Norwegian born Mr. O.Kjelsberg, had the idea of placing the two cylinders of each engine side above each other and to build all locomotives for compound working. Hence the frame was placed inside the wheels, a detail which significantly simplified the mounting of the axles. The pinion wheels were placed on axles supported by the main frame which made the auxiliary one obsolete. On adhesion operated sections, only the lower high pressure cylinders were working, exhaust steam leaving the engine through the blastpipe and chimney. When the engine approached a rack section, steam exhausted by the lower cylinders was directed into the upper ones which drove the pinion wheels through a reduction gear. Both the high pressure and low pressure cylinders had the same volume and to obtain the correct volume ratio the cog wheels revolve about 2.2 times faster than the adhesion wheels. The first locomotive built to the "Winterthur" system was bought by the Appenzeller Bahnen *(photo 4.2.6)*. The Brünig line ordered 18 similar engines *(plan 4.2.7 , photo 4.2.8, technical data 4.2.9)*. Supplied during the first years of the 20th century they served until the fifties and sixties. About 160 engines using the "Winterthur" system were supplied in all. They had a significantly lower steam and coal consumption, but needed experienced and well trained personnel which was not always possible in some foreign countries. Many of these engines were supplied with Schmidt superheaters.



4.2.7 - Winterthur system locomotive plan for the Brünig line,
Diagram: Courtesy Sulzer/SLM archives



4.2.8 - Brünig line locomotive built to Winterthur system.
Photo: SLM-Hauser collection



4.2.6 - First locomotive built to the Winterthur system and delivered to the Appenzellbahn.
Photo: SLM-Hauser collection

Part three continues in the next Swiss Express and moves onto electric power.

4.2.9 - Steam locomotives of the Brünig Railway

Number built	13	18
Built in	1888-1901	1905-1926
Overall length (mm)	6900	7550
Total wheelbase (mm)	2400	3100
Rigid wheelbase (mm)	2400	3100
Axle configuration	0-B-0	0-C-0
Adhesion driving wheel dia. (mm)	806	910
Cog wheel dia. (mm)	796	860
No. of cog wheels	1	1
Drive	Perm. cpld	Sep. gears
Gear rdn-(adhesion drive)		1:1
-(rack drive)	1:1.8	1:1.2
Effective heating surface (m^2)	54.7	62.2
Grate area (m^2)	0.98	1.3
Boiler pressure (bar)	11.76	13.73
Cyl. diameter -high pressure (mm)	330	380
Stroke-high pressure (mm)	480	450
Cyl. diameter -low pressure (mm)		380
Stroke-low pressure (mm)		450
Starting tractive force (kN)	83.4	118
Max. speed (km/h)- adhn.	20	45
Max. speed (km/h)- rack	13	16
Weight tonnes - loco	21.4	31.6
load	35	60
Total weight train	56.4	91.6
Approx. power output (kW)	250	540
Builder	SLM	SLM