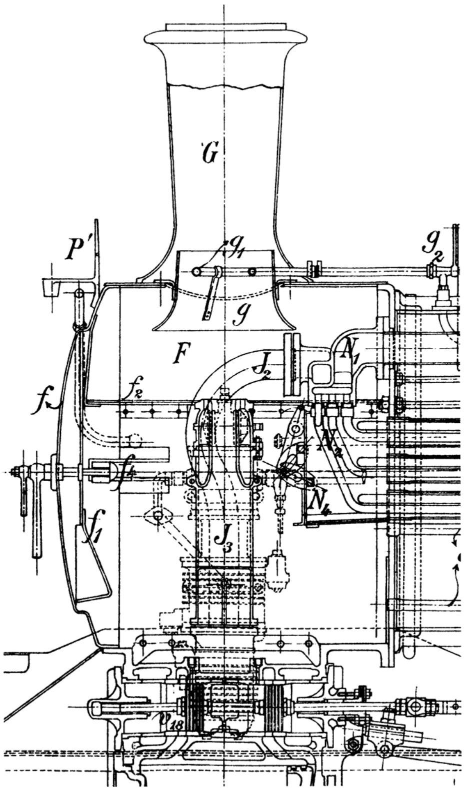
Appendix E: Chimney, blastpipe and orifice

The original drawing of Werkspoor shows a smokebox containing an exhaust orifice of the type of Adam's Vortex with an annular nozzle. According to a list in Part III of the Handboek voor Spoorwegtechniek p 136 the dimensions in NS days were respectively. 168 to 137 mm, which corresponds to a single orifice of 97 mm. The chimney has apparently at the narrowest point, the throat, a diameter of approximately 400 mm. Right away it should be noted that it is too large. The ratio between the mass of the exhausted steam and that of the mixture ejected from the chimney is also present in the ratio of the exhaust orifice diameter to that of the throat. The ratio of 97 to 400 or 1: 4.12 would mean that a large excess of air is sucked along by the HSM locomotives During the tests around 1950 of the locomotives of British Railways it was found that a ratio of 1: 2.85 was quite sufficient. The new exhaust will also receive a similar ratio.



Theoretical background

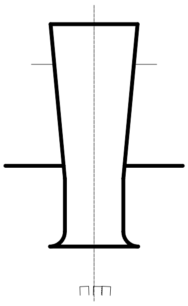
The momentum equation as defined by Zeuner around 1860 is used which states that the vacuum in the smoke box times the size of the sectional area of the chimney is a force that comes into existence because of the difference in momentum of the exhaust steam, and that of the steam-gas mixture that is ejected from the chimney. Impulse is defined by the mass times the speed thereof.

If this equation is used with the common estimated quantities of steam, gas and associated temperatures of the original locomotive it can be shown that a vacuum of about 1000-1200 Pa has been present. The steam issued from the exhaust orifice creates a back pressure of about 43000 Pa. According to the formula of Ell (1953) the exhaust orifice could be of 109 mm diameter, or 84 mm according to Nordmann(1929), the actual size is exactly in between. However, it should be noted immediately that the large chimney necessitates a small exhaust orifice which has the effect that the exhaust jet must have a sufficiently greater velocity to eject the increased amount of steam plus flue gases plus excess air from the chimney.

The downside of the 97 mm orifice is the large exhaust pressure that goes with it: approx 43,000 Pa, 0, 4 bar. The way to address this is to use a multiple orifice.

If the single chimney of the HSM loc would be replaced by 4 smaller ones each of the dimensions of 1/4 of the original, the same exhaust function would remain! That was proven already in 1864 by Nozo and Geoffroy in France with practical tests. It also follows from the assertion ("Pi-theorem") described in 1915 by Buckingham, the one who provided the theoretical background of dimensionless model rules (Reynolds, Mach, and the like.)

The trick with the locomotive is now that we will continue to use the scaled orifices, but not the scaled chimneys. Those will be elongated as high the original chimney. In these relatively longer chimneys, the momentum transfer from the exhaust steam to the gases can continue for a longer time and as a result the exhaust system will work better. This is also clear from the application of double chimneys, Kylchaps of Chapelon, Lemaitres, Giesls and Lemporas according to the recipe of Porta.



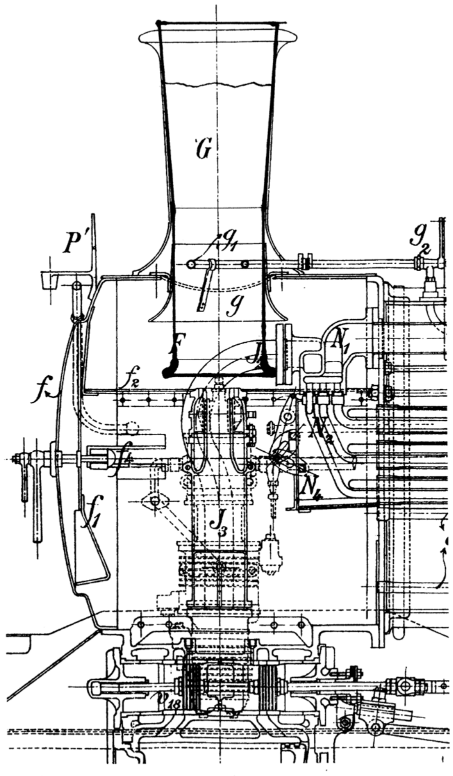
Such a front-end is chosen for the HSM 814, with for 4 orifices. By performing the calculations it can be shown that each of these orifices could be approximately 62.5 mm in diameter. The distance to the throat of the chimney could be 370 mm, the straight mixing section 355 mm and the conical diffuser above 1046.5 mm. The total provides an overall height of 4520 mm above the rails, as high as the NS 3700 and the like.

Calculation

Name		Units	Name		Units
Steam/hr	5744	kg	Orifice diameter	62,5	mm
Steam temperature	150	oC	Orifice area	0,0123	m2
Blastpressure		Pa	Throat diameter	178,125	mm
Gas/hr	10627	kg	Throat area	0,0997	m2
Gas temperature	380	oC	Chimney exit diameter	524	mm
Average Temperature	264	oC	Chimney exit area	0,2156	m2
Rho gas	0,5562	kg/m3	Ideal area reduction	0,6323	
Vacuum	1350	Pa	Area ratio	2,1630	
Steam flux	1,596	kg/sec			
rho orifice steam	0,5094	kg/m3			
Velocity orifice	255	m/sec	Saunders idealised theory:		Units
Calc. exhaust pressure	16594	Pa	steam / mixture ratio	0,9370	
Momentum flux	407	N	Orifice / throat ratio	0,12311	
Vacuum*Area = Force	184	N	Ideal diffuser		
Momentum exit flux	223	N	Ves	83,91	m/sec
Velocity exit	44	m/sec	pg-pes	-258	Pa
Mixture amount	5,115	kg/sec	ideal diffuser	1505	Pa
gas flux	3,520	kg/sec	Total	1763	Pa
gas/hour	12671	kg/uur	According to eq. A.32.8:	1763	Pa
gas/steam calculated	2,206				
gas/steam measured	1,850		Practical diffuser		
Difference	-2044	kg/uur	Ves	84	m/sec
Ratio measured/calcul.	0,839		pg-pes	-258	Pa
rho gas	0,676	kg/m3	diffuser incl. efficiency	1098	Pa
rho steam	0,399	kg/m3	Total	1355	Pa
Volume steam	14395	m3/uur			
Volume gas	15716	m3/uur	Ve exit velocity	38,794	m/sec
Total	30111	m3/uur	Flux exit	4,548	kg/sec
rho mixture	0,5437	kg/m3	Eu number	0,04083	
Eu number	0,04068		Difference Eu nrs	0,00016	

From the calculation above it is clear that the required vacuum of 1350 Pa could be met while, at the same, an exhaust pressure of only 16600 Pa is present, 40% of that of the original NS 5800. This does mean that at the lower-side of the indicator

diagram the pressure is reduced by 0.3 bar. Because this applies to almost the entire piston stroke, while the exhaustport is open, the effective pressure in the cylinder is increased. Franco shows in his comparison of the NS 2100, 3500, 3600 and 3700 that at the speed of 90 km/h the pulling force is reduced to about 1/3 of that at a standstill. That is the force given in the tables which is already determined by 70% of the boiler pressure. Applied to the HSM locomotive this would mean that it would become 1/3 of 70% of 15 bar or effectively 3, 5 bar. This pressure would be increased by 0.3 bar or 8,5%!
Because in an indicator diagram area added at the bottom, when delivering the same power, can be retrieved by shifting the expansion line to the left, this would effectively mean that the locomotive uses less steam when driven.



In the adjacent figure, the diffuser chimney is drawn in. It fits (of course) in the original outside chimney which should be extended slightly.
The four exhaust orifices do get the location of the drawn Adams-vortex orifice somewhat lower in the chimney.

Conclusion
Within the original contours of the engine an improved exhaust can be positioned, which can produce the required vacuum with a lower backpressure.

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