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THE CASE OF A BETTER AMERICAN STEAM LOCOMOTIVE

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Summary:

TRAINS readers will have studied the "Case of the French locomotive" and the reply "The case of the American locomotive", but neither of these soliloquies considered the possibility of uniting the best of both, of improving the best American designs, or stating the possibilities of a fully developed steam locomotive technology incorporating all the progress of the last thirty years.

For the past twenty years almost the only voice in the wilderness pointing out the realities of comparative motive power costs in the U.S.A. has been that of the eminent consulting engineer Harry Farnsworth Brown, who showed that average overall operating costs of diesel main line operation on class 1 railroads had achieved no saving over those with modern steam power due to excessively high capital charges, associated with the very short economic life of major components. The validity of the case so well argued by Mr.Brown in his papers to learned societies in the U.S.A. and in Great Britain, has now been enhanced by the serious effects of the oil crisis.

The U.S.A. transportation system relies for 99% of its fuel upon scarce oil, much of which is imported and subject to political uncertainties. We can expect that railroads will be given a greater share of total transportation requirements on account of their higher efficiency as energy users. But the coal burning steam locomotive offers a dramatic solution: she needs no oil!

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Figures

2. Draughting curves.
3. Proposed high speed design.
4. Proposed Mallet design.

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1. Introduction

The readers of TRAINS will remember two articles, the first entitled "The case of the French locomotive" (1), and the second "The case of the American locomotive" (2), which was in the form of a reply. To the writer both of them seemed like a "talk between the deaf", or as two monologues because each enthusiastically put forward the best side of their respective cases. The first one did not offer any constructive proposals in the sense of taking what was the good from French locomotive developments which could have made an important contribution to American design; whilst the second article had the same, but in the reverse direction. The writer feels that a positive step could be taken by starting from the premise that much can be gained if such mental attitudes were revised, whilst pointing out that the French engineers had already studied and appreciated the best of American locomotive practice and had thus taken their share in the interchange of ideas. (3)

The seriousness of the oil crisis has lead many people to question whether it was sensible to scrap non-oil-burning transportation motive power, and a lot of mea culpa surely are being cried in secret. But time does not stand still and there is no alternative but to look ahead, and the opportunity has come to explore in full what really can be achieved with the best conventional steam locomotive design. Nothing is to be lost in this exercise, whilst other people prepare to spend billions of dollars in searching for alternatives to diesel motive power.

2. The glorious past and its shortcomings

Many pages of TRAINS are full of descriptions and photographs of efficient looking steam locomotives pulling endless rakes of cars of high speed passenger trains, and indeed there was a glorious time in which people were quite happy to enjoy the sensation of peace and safety induced by the iron horse in front. There is a lot of reasons behind her popularity as shown by the undeclining interest in the pages of this Magazine. Yet in spite of all those golden years of steam we must be conscious that those magnificent performances were carried out within a poor frame work of thermodynamic efficiency. Six out of ten photographs show a solid black column of smoke ejected (with a tremendous amount of unutilized kinetic energy thrown to waste), ten feet away from a small stack. Power, huge power, was obtained not by extracting every bit available from a decent theoretical thermodynamic cycle, but by burning inefficiently mountains of coal carried on enormous tenders.

Whilst American engineers did understood the meaning of increasing the overall efficiency by enlarging the upper limits of the theoretical steam cycle, namely higher steam pressures and temperatures and feed water heating, they failed to realize in full the importance of the lower limit-exhaust back pressure, which, for example absorbed about 1400 h.p. in the Penssy T.1 at full power- about one fifth of the total power of the locomotive.

To save a pound of back pressure is worth an increase of thirty pounds in boiler pressures. Yet nobody is able to assess all the mishaps coming after the unfortunate work of Young (4) on exhaust design, which lead to the poor proportions, high back pressures and heavy blast characteristic of American locomotives: which certainly did not have the best draughting arrangements in the world! (Fig. 2)

Internal streamlining, the magic key to Chapelon's techniques was too late and imperfectly understood. The highest boiler pressures were wasted in poor piston valves, small steam passages and unnecessary throttling. Fig. 1 shows a typical indicator card of the well known K 4s. Specific steam consumption was not as low as it could have been at full power and so enormous boilers were required to produce the necessary steam, thus entailing unnecessary carrying wheels and weight, a heavy coal bill and showers of sparks making an unwanted cinder carpet of the right of the way! The poor draughtingarrangements could not be improved to give smokeless combustion and a free steaming boiler; no one will say that such a state of affairs was conductive to efficient operation!

Briefly, the following equation was not fully understood:

$$\text{Maximum power produced} = \frac{\text{Maximum steam produced}}{\text{Specific steam consumption}}$$

While the importance of the numerator was appreciated, that of the denominator was not, nor was the interrelation between the two.

The size of the grate as the most important feature of the boiler was seldom recognized at all, and its lesson not understood. Consequently the best qualities of coal were insisted upon, thus imposing limitations and a higher fuel bill.

Cylinder insulation was a bare minimum, perhaps just to comply with the conscience: this huge piece of ironmongery was cooled by a gallant air stream, and re-heated at every start. Engineers seemed to forget that, as a heat engine, a steam locomotive has to work in an hostile environment and that intermittent operation was inherent.

The blower! It was as inefficient as it could be, and used and abused as much as possible. How much air was unnecessarily heated in oil burning engines when standing by?

Whilst the above list of shortcomings could be enlarged even further we must state the other side of the case: American engines were mechanically sound, most reliable and capable of almost continuous operation, getting the most out of their capital investment in terms of ton miles per day. An excellent example of this is that the American 14 R's operating in France were the last steamers to be retired, a high tribute to their reliability in view of their undeniably heavy fuel consumption. To the writer who has worked with engines coming from many prestigeous locomotive building countries, there is nothing like the American design for rugged construction and reliability.

Compounding's virtues were not fully realized in the U.S.A. and the failure to appreciate that poor internal streamlining, particularly between the HP and LP cylinders was the cause of the poor results obtained when higher speeds were sought.

3. Harry Farnsworth Brown logical motive power cost analyses.

Probably few Americans have realized that the most important piece of the evidence for the steam locomotive in the diesel-steam comparison was produced by Harry Farnsworth Brown, an electrical engineer of New Haven. (5)

His case, based on an exhaustive study of motive power operating costs for the retention of steam power in coal burning areas of the country was given in papers in the U.S.A. and England, very many pages where the discussion was so important that the President of EMD of General Motors crossed the ocean and went to London. Mr. Brown's paper made a considerable impact there, but unfortunately came too late to reverse British decisions on dieselisation.

Harry Farnsworth Brown is not an enthusiast, but an electrical consulting engineer. He realized the shortcomings of a so called electrical locomotive which carried its own costly prime mover, and calculated the data for Table I. An updating of Mr. Brown's calculations to 1967 showed similar result.

Thus Mr. Brown showed what could be expected from U.S.A. railways if operated by modern steam power, and with further developments in design of steam power these could be improved on considerably.

4. What could have been.

While fully respecting the technological tradition which have contributed to the well being of the community it served with billions and trillions of tons transported over lengthy distances, it is interesting to carry out the exercise of exploring what could have been achieved by a modern American engine if properly "thermodynamized ". Let us take as an example the Big Boy, which can be regarded as a high water mark of American steam locomotive engineering.

One of those locomotives could develop as much as 7000 horsepower at the drawbar, her furnace eating 10 tons of coal per hour ... with a thermodynamic efficiency of ... 60% of what could had been possible!

The following are the most important non structural design improvements:

* Adoption of the Kylchap, Giesel or Kylpor blast pipe to achieve a drastic reduction of back pressure down to 6 psi at maximum rate of working instead of about 25 psi. This alone would increase the maximum power by about 1500 h.p.!
* Substitution of the exhaust steam injector by a closed feedwater heater giving a 130°C feedwater.
* Adoption of air tight ashpan dampers to control fuel consumption during stand by.
* Adoption of the gas producer combustion system.
* Adoption of an exhaust steam air heater.
* Rising the steam temperature by throttling gas flow through the small tubes, thus diverting more gas through the superheater flues.
* Improving the steam tightness of superheater elements against the header.
* Through improvement of cylinder insulation.
* Substitution of multiple, narrow rings "diesel quality and make" for existing wide rings for valves and pistons.
* Minor but significant improvements to the internal streamlining of the piston valves.
* Slight alterations to the valve gear to give longer valve laps.
* Adoption of the "Precision" type of valve gear power reverse.
* A thorough enquiry into minor defects to be corrected.

It can be expected that the above non structural design improvements will rise the actual drawbar horsepower from 7000 to 10000 (a 40% increase), making an equivalent to 13000 diesel HP, while the coal consumption could be cut down by some 40%. The gas producer combustion system would make the significant contribution of allowing such performance to be achieved with cheaper "second class" coals whilst its high combustion efficiency will result in clean, non pollutant cinder free exhaust.

5. What can be done

Whilst the above list shows sizable improvements that would enhance the position of steam power in Harry Farnsworth Brown's analysis,it still follows the basic layout of existing engines and therefore does not take full advantages of all the possibilities inherent in a brand new design. Improvements in the theoretical limits of the thermodynamic cicle can of course still be found without abandoning the extraordinarily successful stephensonian constructional layout of the traditional steam locomotive, which has outlasted a lot of attemps to achieve progress through unconventional designs such of those by Leoffler, Schmidt-Henschel, Krupp, Ljumstrom, General Electric, Penssy and LMS turbomotives, Kitson Still, James Archibald and many others.

As a matter of fact, further improvements can be carried out -further than the Chapelon French designs- in the way the real engine's thermodynamic cycle approaches the already improved theoretical cycle. This essentially involves the following points:

a) Internal streamlining carried out to the utmost so as to allow full advantages to be taken from compounding and highest volumetric horsepower obtained with modest piston thrusts.

b) Full consideration must be given to the fact that a steam locomotive is inherently an intermitent working machine.

c) The actual achievement of the most sophisticated technical development compatible with easy driving techniques.

Fig. 3 shows a proposed high speed design worked out for 125 mhp timetables (not requiring, for example, any of the sophistications of the British APT), that could be built almost immediately and without recourse to still unknown technologies. The expected drawbar performance will be 4000 HP for a 100 ton engine, and its coal consumption not greater than 50% of the best achievable with a postwar design.

Because of the cumulative effects of the various improvements, a low axle load results (about 40 000 lbf). This, coupled with the low impact factor inherent in the exclusion of nose suspended motors, leads to a much required reduction in track maintenance.

Fig. 4 gives an outline of proposed Mallet built to the less highly stressed standards (yet incorporating roller bearings), capable of reaching a 10000 HP figure at the drawbar but with a piston thrust (the Achilles heel of high American horsepowers!) of no more than 130.000 lb, working on "second class coal" and requiring neither inexpensive nor critical materials.

6. Conclusions

The impact of the oil crisis upon U.S.A. transportation system has been shown to be a formidable one, since actually 99% of it depends on oil products. As a matter of fact railroads will be entrusted by the community with a bigger share on those duties, and it is difficult to imagine which can be the diesel lobby's arguments defending their selling policy which requires railways to operate on oil products, involving the whole nation in a major political effort to secure oil imports at ever increasing cost.

While electrification will of course be invoked as an alternative, the people favouring it will probably ignore the possibilities with steam which they did not see and about which they cannot be conversant. But if oil is already a scarce commodity, copper is just second to it, and it is good to remember that a copperless electrification is still a dream.

Heavy investments are the other inconvenience of electrification which shows a dangerously rising tendency on rates of return on capital needed to amortise the capital first cost. The community is becoming steadily more aware of the effects of immobilizing money in static equipment and this is shown by the clear trend of allocating capital investment solely on the schemes with the highest return.

Have American railroads enough traffic intensity to justify all out main line electrification programmes or can this be justified economically only on a limited number of fairly short sections carrying very dense traffic?

Really modern steam deserves at least to be given a fair evaluation if it can be applied within the most stringent parameters of thermodynamic efficiency, far removed from the fuel-wasting philosophy prevailing in the past. If it can be achieved by development of conventional technology, so much the better.

More or less lengthy arguments can be produced to prove the validity of the case but there's just one cardinal point making any scheme a matter of "to be or not to be": the will to succeed. No steam locomotive development, however technically advanced and commercially successful it could be, can become useful to the community unless the strong will and determination necessarily associated with any real progress is applied and sustained. Therein lies the key to success or failure.

TABLE I

Comparative costs diesel operation versus operation with equivalent modern steam on basis of 1957 costs

	Diesel		Steam	
	Cost	Saving	Cost	Saving
<u>Road power</u>				
Repairs:				
Diesel and equivalent steam	377.4		293	
Other	51.6		51.6	
Fuel:				
Diesel and equivalent steam	366.7	85	451.7	
Other	23.2		23.2	
Engine men	388.3	19.4	407.7	
Engine house expense	104.2	22.3	126.5	
Water	5.3	26.9	32.2	
Lubricants	27.2		7.7	19.5
Other locomotive supplies	8.8		8.8	
Total road locomotive expense	1352.7	153.6	1402.4	103.9
Net operating savings		49.7		
<u>Yard power</u>				
Repairs:				
Diesel and equivalent steam	76		52.8	23.2
Other	8.1		8.1	
Fuel:				
Diesel and equivalent steam	40.5	77.5	118	
Other	3.4		3.4	
Engine men	242.7		242.7	
Engine house expense	29.9	15.6	45.5	
Water	1.1	18.7	19.8	
Lubricants	4.4		3.1	1.3
Other locomotive supplies	2.2		2.2	
Total yard locomotive expense	408.3	111.8	495.6	24.5
Net operating savings		87.3		
Total expense, road and yard	1761.0		1898.0	
Total net operating savings		137.0		24.5

TABLE I (cont.)

<u>Investment</u>				
Road locomotives	2760		1925	835
Yard locomotives	1120		555	565
Total locomotives	3880		2480	1400
Facilities (pro-rated 300 road, 100 yard)	400			400
Total investment	4280		2480	
Net saving in investment				1800
<u>Fixed charges</u>				
Depreciation of equipment:				
Road	165.6		61.0	104.6
Yard	50.4		17.5	32.9
Interest on undepreciated equipment:				
Road	55.2		38.5	16.7
Yard	22.4		11.1	11.3
Total fixed charges,equipment	293.6		128.1	165.5
Total, all charges road	1573.5		1501.9	71.6
Total, all charges yard	481.1	43.1	524.2	
Total, all charges road and yard	2054.6		2026.1	28.5

(All figures in millions of dollars)

References:

Economic Results of diesel electrictmotive power on the railways of the United States of America by H.F. Brown, Ph.B., Fellow A.I.E.E. Proc. Inst. Mech. Engrs - Vol 175 N° 5, 1961

References

1) R.K. Evans. "The case for the French Locomotive". Trains, December 1966, p. 25-41.

2) V.L. Smith. "The case for the American Steam Locomotive". Trains, August 1967, p. 22-27.

3) A. Chapelon. "Les leçons de l'expérience ferroviaire américaine après un voyage aux Etats Unis". Bull. de l'Association Française des Amis des Chemins de Fer", mai-juin 1939.

4) M. Young. Bulletin 256. University of Illinois.

5) H.F. Brown. "Economic Results of Diesel Electric Motive Power on the Railways of the United States of America". Proc. Inst. Mech. Eng. 175 (1961) Pts. 257-317.

"Locomotive Repair Costs and their Economic Meaning to the Railroads of the United States". ASME/AIEE Railroad Conference, Pittsburgh, April 20-26, 1960.

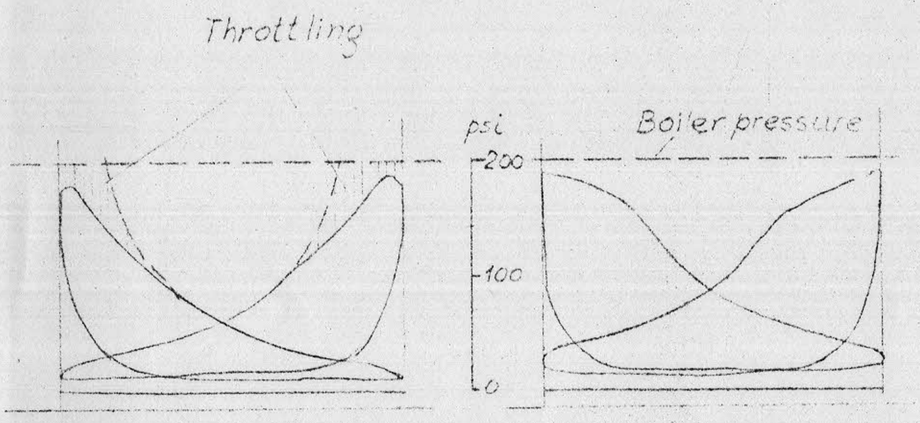
"The Diesel Locomotive - The Other Side of the Coin". Circulated in 1968 by Gibbs and Hill, consulting engineers.

Proposed design for a high power Mallet

The two groups of driving wheels are connected mechanically by a modified Luttermöller geared drive to correct the tendency to slipping. No provision is made for simple working at starting, yet the starting tractive effort is not less than 168 000 lbf, which can be sustained until some 30 mph. At this speed sustained maximum horsepower is guaranteed to be over 10 500 at the drawbar in full gear, which is equivalent to some 15 000 diesel rated horsepower. This is obtained with an axleload not greater than 60 000 lb with very little dynamic augment on account of the excellent balancing of the inter connected engine groups .

The front engine unit is designed as a three cylinder unit to provide the required low pressure cylinder volume within the loading gauge.

Ample steam port area (1/4 of piston area) is provided by twin long travel piston valves so as to avoid excessive size. Indicator diagrams are expected to be as good as those obtained using poppet valves. The locomotive frame is not intended to be necessarily of the cast steel bed type: conventional bar frames being adequate provided proper means of attachment to the boiler are provided.



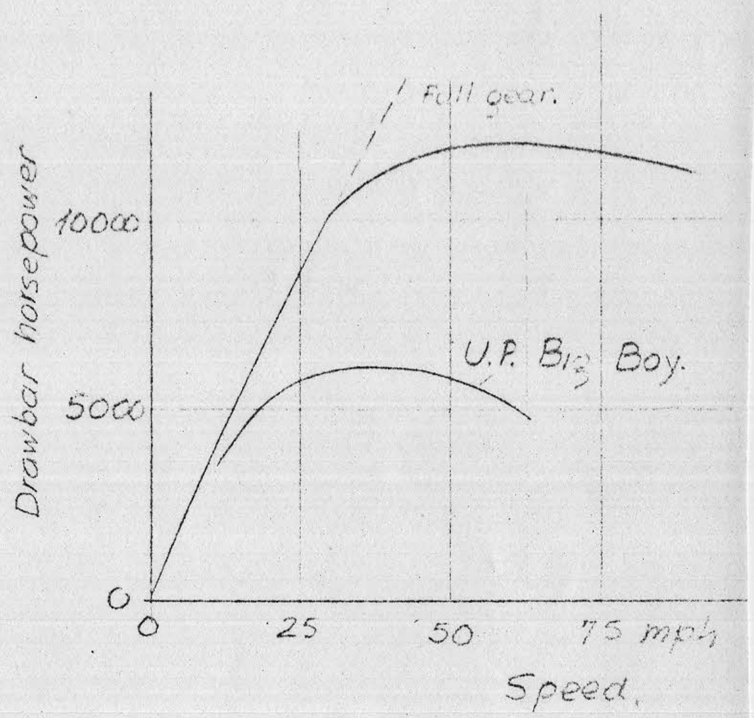
Test 4033 Year 1915.
2350 I.H.P.
36,7 % cut-off
66 mph.

Piston valves.

Test 904 Year 1940.
3790 I.H.P.
34 % cut-off.
66 mph.

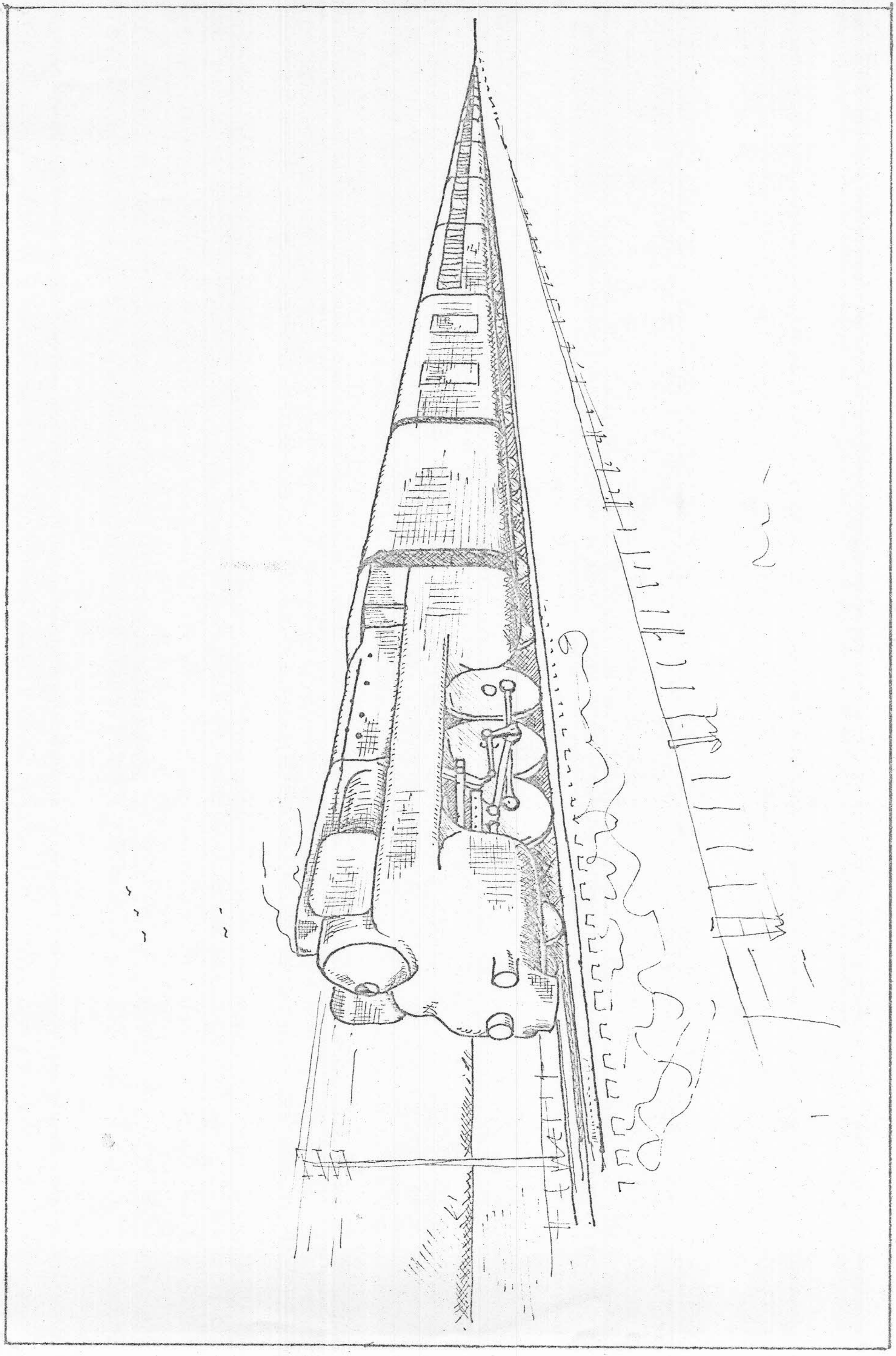
Franklin gear.

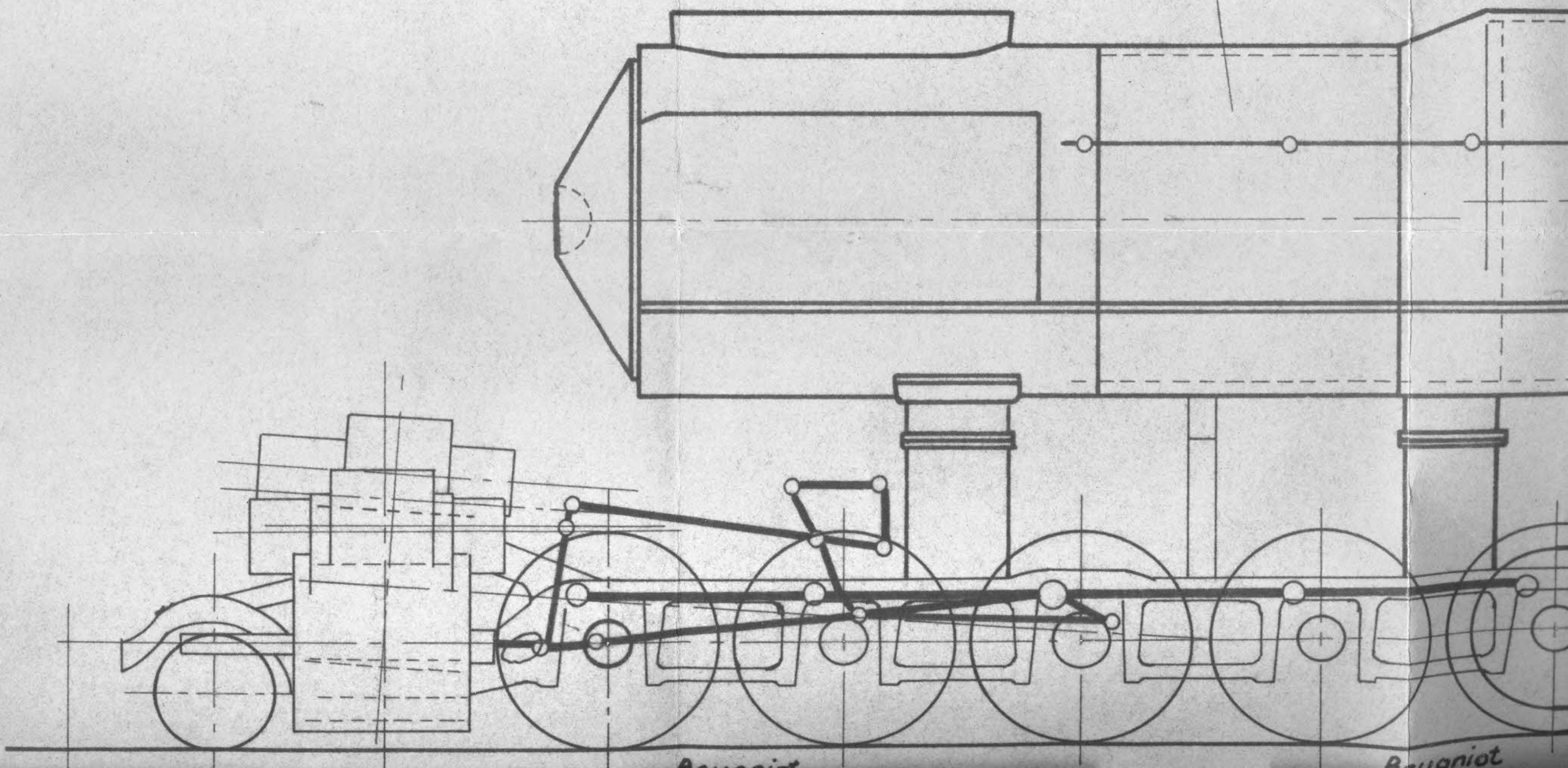
Fig. 1. Indicator diagrams, P.R.R. K4S.

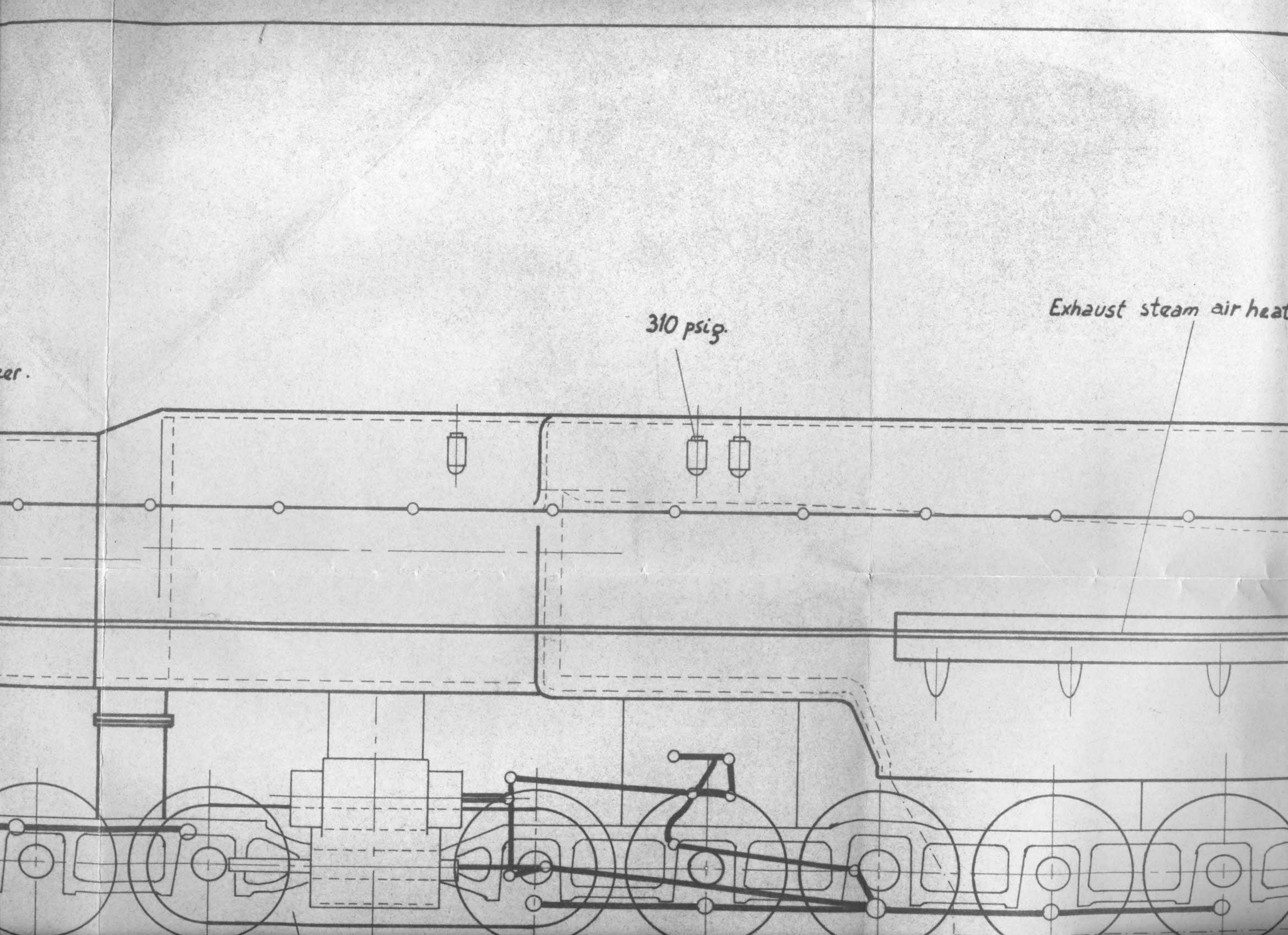


Proposed design 2-10-10-2

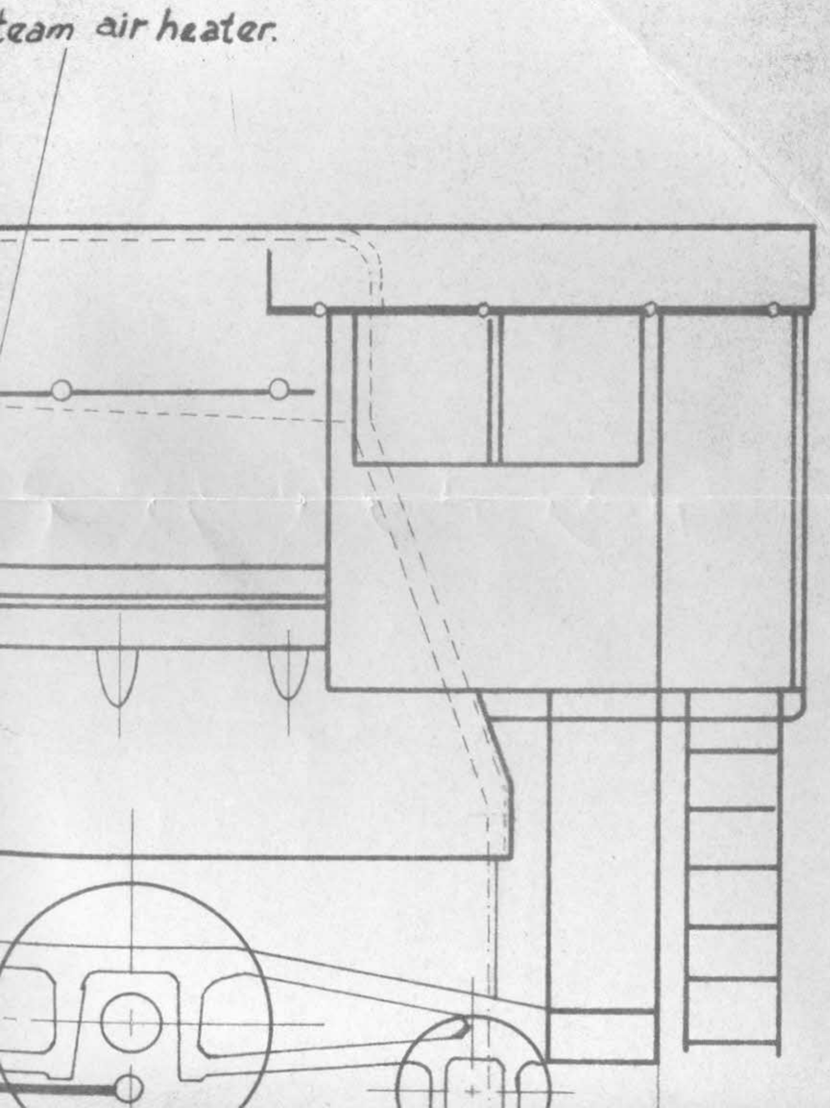
Drawbar horsepower curve.

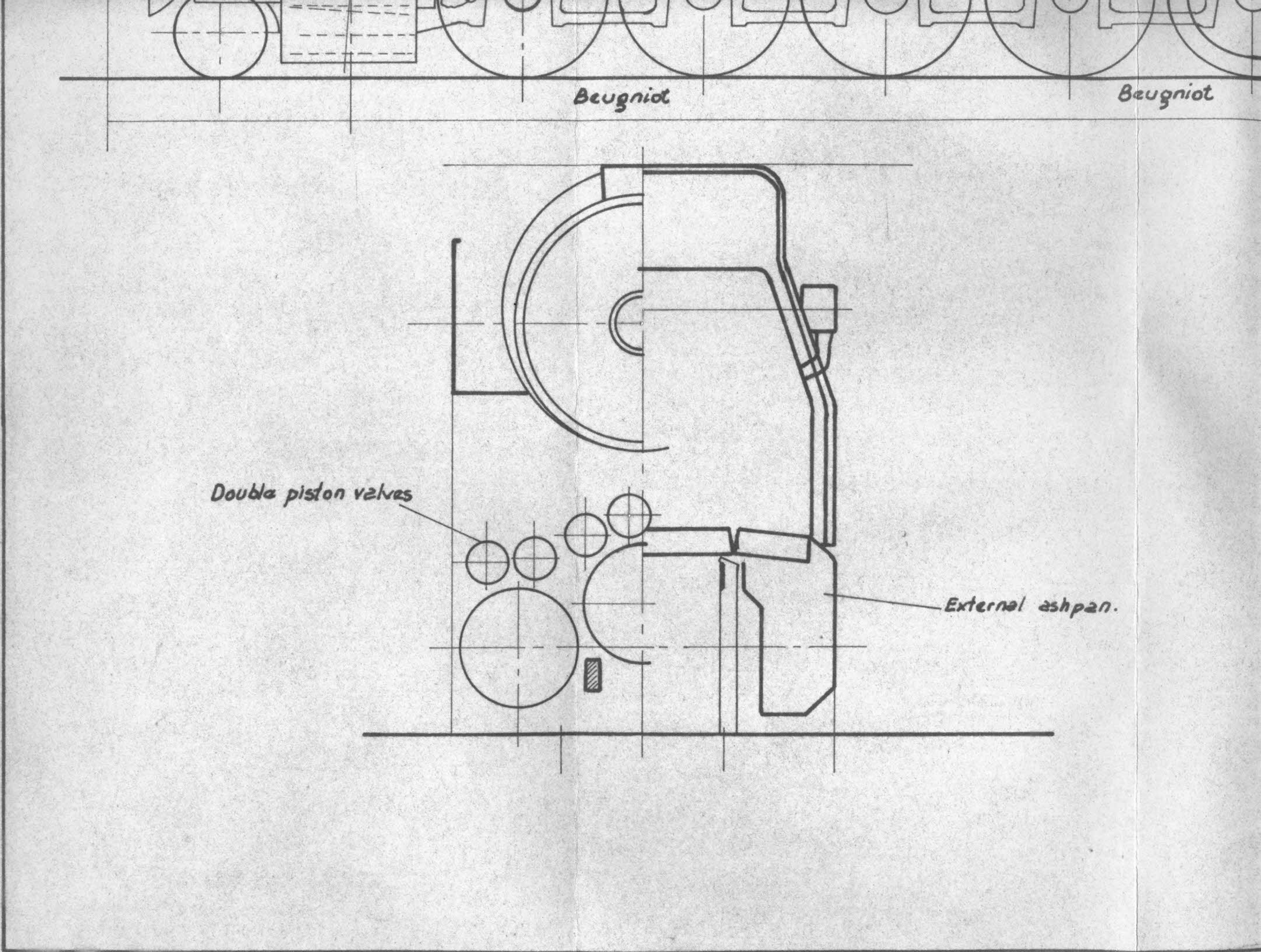


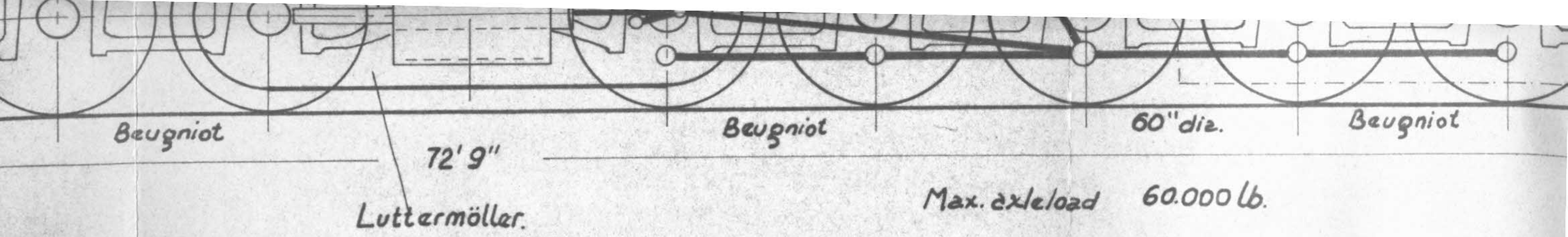

Economizer.



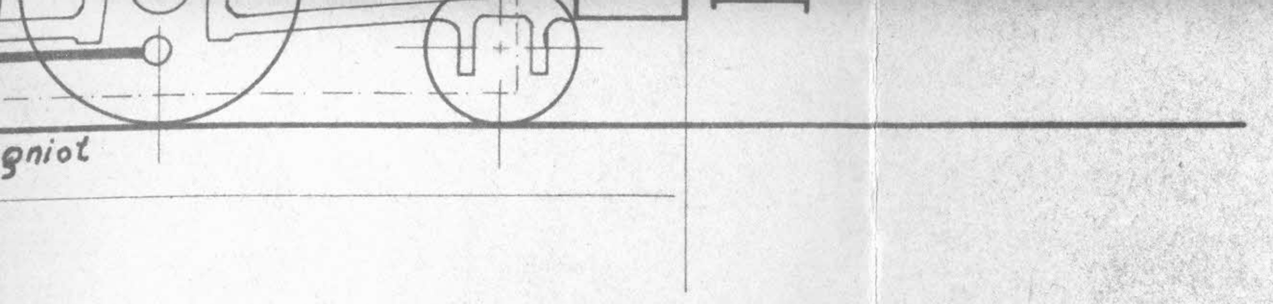
…er.
310 psig.
Exhaust steam air heat…


team air heater.


Beugniot
Beugniot
Double piston valves
External ashpan.


Beugniot
Beugniot
60" dia.
Beugniot
72' 9"
Luttermöller.
Max. axleload 60.000 lb.

l ashpan.



PROPOSED MALLET.