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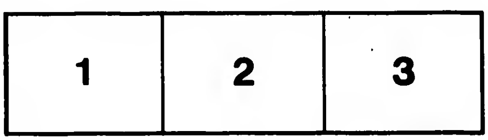
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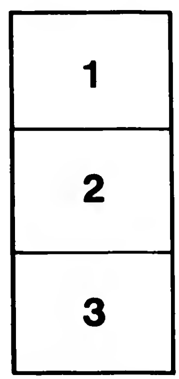
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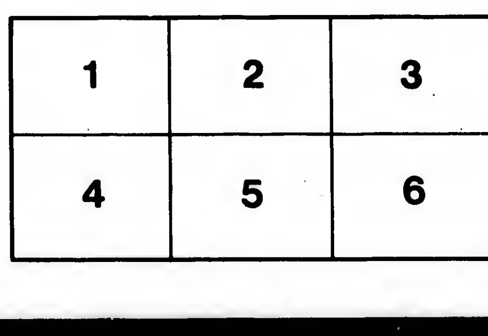
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THE

American Railway Master Mechanics' Association.

REPORT OF COMMITTEE

ON

Compound Locomotives.

Gentlemen :

The slight experience America has had with the compound locomotive, although elsewhere there are between six and seven hundred in successful service, so contracts the possible field to be covered by a report on the subject assigned to us, that we, of necessity, must go beyond the limits of this land and of this association for the major part of our facts; and in expressing opinions and conclusions, are compelled to take for granted a fair acquaintance with its modern literature, giving the experimental results of trials carried on outside the American continent.

To commence with—and as a help in the direction of narrowing the province to be covered by this report—we would suggest for discussion the following questions, viz.: 1st. Is increase of boiler pressure an essential element in the success of compounding? 2d. What gains have followed compounding? 3d. What are said to be its losses? 4th. What, per engine, is the increased first cost of compounding? and 5th. Does the saving more than balance this cost? 6th. What are American conditions for locomotive service, and can the compound locomotive meet them? 7th. Is it an essential defect of the compound that it must be short of starting power? 8th. Give a brief summary covering some details and peculiarities common to compounds.

1st. Is COMPOUNDING OF ANY VALUE WITHOUT INCREASE OF BOILER PRESSURE? This query is due to the repeated assertion that in compounding there was not, and could not be, an economy in steam consumption, except the boiler pressure be decidedly increased, raised to 170 lbs., or even higher. The results of the experiments of Mr. T. Urquhart, locomotive superintendent G. and T. Railway (Southeast Russia), contradict this statement. The trials cover a period of ten months, in the same class of service, with simple and compound engines practically of the same weight, and all with pressures of 135 lbs., and they show for the compounds a general average saving in fuel of 18 per cent.

Apart from this solution of the vexed question of pressure, Mr. Urquhart's experience is unusually interesting, because the experiments were carried out in cold weather, with oil fuel, which has a more uniform heating quality than soft coal; and the delivery of the fuel into the firebox was almost automatic, thus practically getting rid of the "personal factor," for which it is always necessary to allow in comparing special and brief experiments.

Mr. C. Sandiford, of the N. W. Railway, Lahore, India, reports a 13½ per cent. economy with unaltered, but still lower, pressures, viz., 120 lbs., the saving being the same whether the steam was used in two or four cylinder (tandem) engines.

These results will not surprise those who are familiar with exactly parallel cases in other forms of steam engineering.

Do not misunderstand us to say that there are no economies in higher pressures. There are wide possibilities with high temperature; and the many published figures, from recent trials, stoutly confirm our opinion. But under this leading heading, the committee wished to emphasize the fact that compounding, at ordinary working pressures, has its own value as an economizer of steam, without keeping hid the sister fact that higher pressures give an additional possibility. And it should not be forgotten that very high pressure steam has, so far, only been fully utilized by passage through more than one cylinder.

Higher pressures and very early valve cut-offs, for simple engines, have had a fair trial on many of our railroads; nevertheless, to-day initial cylinder pressures above 150 lbs. are rare; and we believe that when boiler pressures higher than 160 lbs. are retained, it is with the object of making the boiler a reservoir of power for starting and grade climbing, rather than with a confirmed faith that very early cut-offs lower the fuel bill.

The Saxony Railroad report increasing their boiler pressures for simple engines from 8½ to 12 atmospheres (say from 120 to 175 lbs.), without resultant economy; whereas 212 lbs. has not proved too high for convenience or economy in the compound practice of the P. L. and M. Railway (France).

2. WHAT GAINS HAVE FOLLOWED COMPOUNDING? (*a*) It has achieved a saving in the fuel burnt averaging 18 per cent. at reasonable boiler pressures, with encouraging possibilities of further improvement in pressure and in fuel and water economy. (*b*) It has lessened the amount of water (dead weight) to be hauled, so that (*c*) the tender and its load are materially reduced in weight. (*d*) It has increased the possibilities of speed far beyond 60 miles per hour, without unduly straining the motion, frames, axles, or axle boxes of the engine. (*e*) It has increased the haulage power at full speed, or, in other words, has increased the continuous H. P. developed, per given weight of engine and boiler. (*f*) In some classes has increased the starting power. (*g*) It has materially lessened the slide valve friction per H. P. developed. (*h*) It has equalized or distributed the turning force on the crank pin, over a longer portion of its path, which of course tends to lengthen the repair life of the engine. (*i*) In the two-cylinder type it has decreased the oil consumption, and has even done so in the Woolfe four-cylinder engine. (*j*) Its smoother and steadier draught on the fire is favorable to the combustion of all kinds of soft coal; and the sparks thrown being smaller and less in number, it lessens the risk to property from destruction by fire. (*k*) These advantages and economies are gained without having to *improve* the man handling the engine, less being left to his discretion (or careless indifference) than in the simple engine. (*l*) Valve motion, of every locomotive type, can be used in its best working and most effective position. (*m*) A wider elasticity in locomotive design is permitted; as, if desired, side rods can be dispensed with, or articulated engines of 100 tons weight, with independent trucks, used for sharp curves on mountain service, as suggested by Mallet and Brunner. One such engine of 80 long tons is now under construction.

3. WHAT LOSSES ARE SAID TO HAVE FOLLOWED COMPOUNDING? (*a*) In some particular types, as actually proportioned, a loss in starting power of from 15 to 20 per cent. However, loss of power in starting cannot be said to be a defect in the principle of compounding. (*b*) An increase in the number of parts. They are few and plain in the two-cylinder engine, entailing little outlay in first cost or in repair. (*c*) A possible, but, this committee thinks, not probable increase in the cost of repairs to the boiler, per pound of fuel burnt, if higher pressures are used. Positive information on this point is difficult to obtain. (*d*) An increased cost of repairs

to the engine per mile run. This item is not yet large enough to be measurable, after three years' continuous service in the plainer forms of the two-cylinder compounds. (*e*) A larger percentage of failures on the road due to greater complication and size of parts. (*f*) Increased reciprocating weights on one side, either not balanced, and so increasing the deflection of the engine, or, if approximately balanced, the balance weight doing injury to the roadbed, etc. The two last sections seem to be pure suppositions, which, after search, we find no evidence to sustain. (*g*) Want of variability or adaptability to wide extremes in speed, and to amount of work to be performed; so that a large compound does not work as cheaply when hauling light loads, or running without load, as a simple engine does.

It is not proved that a compound, working properly throttled, that is, with steam wire-drawn, may not have actually, as she theoretically has, a wide and economical adaptability. So that if the compound, like any other motor, be not as economical when exerting low power as when exerting full power, it probably will use less steam than the simple engine of same weight, working under similar conditions of light haulage duty.

However, the one thing certain about "American conditions" is that no large portion of our motive power does run lightly loaded, and until we have a wider experimental experience, it is not recommended that all locomotives, doing branch and local light service, be built compound.

4th. WHAT IS THE INCREASED FIRST COST PER ENGINE? M. V. Borries has published figures giving cost. In speaking of his own design of engine, he says they can "be built 2 to 5 per cent. cheaper than single engines of the same power—not of the same maximum tractive force; because this power depends upon the boiler, which might be 10 to 15 per cent. smaller for the compound engine. If the same boiler is kept, as is commonly the case, the compound engine would be some 2 or 3 per cent. heavier, and 4 or 5 per cent. more costly than a simple one; but, with properly dimensioned cylinders, 10 to 15 per cent. more powerful than the latter. For equal work the compound engine would always be the cheaper engine." Mr. E. Worthington says: "The intercepting valve and copper pipes forming the receiver, and the patterns for two different sizes of cylinders, are the chief items which raise the cost of a two-cylindered compound locomotive; while engines with three or more cylinders have additional parts, which considerably increase their cost. In engines with four cylinders, the tandem system is cheaper than the receiver system. Tandem cylinders are, however, objectionable, because the pistons are difficult to examine; but the receiver system is ready of access, and affords an opportunity of heating the intermediate steam by circulating it among the waste gases of the smoke box; and, by isolating the high-pressure and low-pressure cylinders, an advantageous difference of temperature is maintained between them."

"The cost of constructing a number of two-cylindered locomotives does not greatly exceed that of the same number of ordinary engines. The cost of three-cylinder locomotives may exceed that of simple engines by $1,000 to $1,250 each."

The cost of changing simple to two-cylinder engines need not exceed $250 to $300 each, if the expense of drawings, patterns, and templets be divided over a series of engines. The additional cost of building a two-cylinder engine, with receiver, etc., as used by the M. C. Railway, or the ingenious form of four-cylinder engine, as used by the B. and O. Railway, need be little, if anything, over $200 (excluding royalties), or say from 2 to 2½ per cent. increase on the cost of a simple engine.

5th. Does the saving more than balance the increased first cost? If, for convenience, the fuel saving be taken at 17 per cent., or 1-6, and the gross consumption at 900 tons per year, with coal at $1.50 per ton, the decrease in the annual fuel bill is but $225. Certainly not a wide margin to cover contingencies. If, however, at first only the more powerful engines are compounded, whose consumption averages 1,200 tons per year, and coal, as is common, costs on tender $3 per ton, the saving on fuel is $600, or two cents per mile on a mileage of 30,000 per annum. As this amount would cover not only reasonable interest on first cost, but also allow for about 33 per cent. increase in total expenditure for motive power repairs and renewals, the saving is certainly enough to permit a possible, but, we think, not a probable, largely increased cost of engine repairs, and yet have a margin of saving on the final balance sheet to the credit of the compound.

6th. What are "American conditions" for locomotive service? Can the compound engine meet them? We have given this section a large amount of attention, because it has so often been said that the compound must, to be successful on this continent, be adapted to suit American conditions, and your committee naturally were desirous of fully understanding these conditions. They have not been specified by those making the assertion; and we must reluctantly confess to having failed to identify, much less define them, so that after a long, unsatisfactory chase, they appear to us to be somewhat mythical. If any member can, and will, specify them, he will confer a favor, at least upon the committee, if not upon the association.

If an American condition be large starting power, then the Malett two-cylinder and all four-cylinder engines easily have cylinder power in excess of their adhesive weight. If American conditions be ability to do satisfactory work on a second-rate or third-rate roadbed, or simplicity of construction, or easy accessibility of parts, then these conditions are met by any two-cylinder engine, or by the B. and O. Railway four-cylinder engine.

Apparently neither climate nor men are factors in this equation; as compounds are a success in the hands of ordinary enginemen in partially civilized countries; and in hot climates, as well as in Russia, under conditions of low temperature and snow as trying as those ordinarily met with inside of 51 degrees, the present northern limit of our railway belt.

7th. IS IT AN ESSENTIAL DEFECT OF COMPOUND LOCOMOTIVES THAT THEY MUST BE SHORT OF STARTING POWER? Certainly not! The starting power of the Malett type is at least equal to that of a simple engine of the same weight, and its cylinder power can easily be made to exceed it, by allowing more than half boiler pressure in the large cylinder for the first few revolutions. In the V. Borries, Worsdell, Pitkin and other two-cylinder types, and the Lepage three-cylinder engine, their starting power (as Prof. Woods has graphically illustrated), at 170 lbs., may be greater than that of a simple engine at 150 lbs., having cylinders of the same size as the high pressure, *during the first half revolution*, but that after this the power (at low speed) of the compound diminishes to 80 or 85 per cent. of that of the simple engine. This conclusion is modified and improved by the knowledge that all two-cylinder engines originally designed as compounds have, or should have, their small cylinder larger than the cylinder of the simple engine of corresponding weight or duty.

It is possible, with the Lindner or equivalent form of starting valve—and a painstaking engineman—to get about 90 per cent. of the starting power of a corresponding simple engine. The Webb type of three-cylinder engine (except with the low-pressure crank dead on center) has cylinder power enough to slip both pairs of wheels, and no higher starting power is desirable. What may be called the opposite form of three-cylinder engine (the Sauvage type), with cylinders of approximately the same diameter, as used on the Northern Railway of France, has ample starting power, because the full boiler pressure is admitted direct to the two low-pressure cylinders. In fact, if desired, the locomotive can be continuously so worked, viz., as a simple engine. Tandem and other forms of four-cylinder engines are not wanting in starting power. The B. and O. Railway engine in starting, with a gear as simple as the water-tap gear, puts the small piston practically into equilibrium, and thus admits high-pressure steam to the large cylinder.

A mean effective pressure of 90 lbs., in a simple 18x24 in. engine, will start a train of 13 coaches on a level in a lively fashion, and a compound can easily give the equivalent of that total pressure, without being over-cylindered.

Going back to the two-cylinder style of engine, with automatic intercepting valve, and limited size of cylinder, it would seem as if all of them were capable of getting into motion the load they were designed to haul at full speed, so that their limitations are that they do not get away quite as smartly, quite as noisily, or with the same tearing effort on fire and fire-box, as do certain simple engines that waste both fuel and steam in starting. The comparative difference, in time or distance, required by this class of compound to attain maximum speed, has not yet been shown by experiment, but is probably less than is generally supposed.

Mr. Urquhart, desiring to settle the question of the tractive power of simple engines altered to compound, with one cylinder unchanged, and with boiler pressure unchanged, carried out tests, using both indicator and dynamometer; and he reports that at a speed of 10 miles per hour the compound passenger engine suffered the following diminution, viz., in first notch, 42 per cent.; in second notch, 28 per cent.; in third notch, 17 per cent.; in fourth notch, 7 per cent.; and in fifth notch, or full gear, 5 per cent. And a similar test of the freight compound showed, in the first notch, 27 per cent. loss; in the second notch, 17 per cent.; in the third notch, 10 per cent.; and in the fourth notch, or full gear, 5 per cent. He goes on to say that, for all practical purposes, in full gear a 5 per cent. difference, at this speed, may be neglected.

8TH: GENERAL.—A recent press notice credits Mr. Webb with an attempt to reduce first cost, by throwing away the valve gear for the low-pressure cylinder, and using in its place a single loose reversing eccentric—in other words, with an attempt to use an invariable cut-off for the large cylinder. And such practice is not unreasonable, if it from the first be acknowledged that the compound is designed for doing a maximum specific duty with high economy, and, therefore, the valve gear cannot be, and is not, arranged for a wide variability of service.

This intention in design most clearly marks all those engines using but one valve, or one valve stem, to distribute the steam to both high and low pressure cylinders; such, for instance, as the Vauclain piston valve, the Woolfe hollow D valve, and the Dunbar single valve stem. In the two first mentioned most ingenious valves, the release of the high-pressure cylinder must be at the same moment as the admission to the low-pressure, or it is no actual release; and the cut-off in the low-pressure cylinder marks the exact point when compression in the high-pressure cylinder commences, there being no appreciable "receiver" capacity in the valves themselves, large as the passages through them have to be. There is, then, it is clear, little elasticity of adjustment in such valves and gears. The cut-off being early in the small cylinder, it must be early in the large, and as a result the compression in the small cylinder is enormous. Thus the conclusion is again brought home to us that the control of the compound, when small horse power is to be developed, must be chiefly through the throttle wire-drawing the steam, and thus reducing the initial pressure.

Putting emphasis on this truth will not frighten those who are familiar with the fact that wire-drawing is common to-day with our best enginemen. And it may here be noted that the *imperative necessity* for this so-called "crude practice" is the full explanation for the slight use in modern locomotives of screw and other finely divided reversing gears. This statement opens up the whole matter of cylinder condensation, but it is too large a matter to be properly treated in this report.

However, such modern experimenters as Westinghouse, Kennedy, etc., prove that wire-drawing the admission into cylinders of large surface and small volume is more economical than valve cut-offs at less than 50 per cent. of the stroke.

There are some constructive details and peculiarities about compounds that may deserve special mention. For instance, it is judicious to put safety or relief valves on the low-pressure chest or cylinder, but they should be so located or guarded that in case they came into action, they should not smother the engineman with steam, and obscure his vision. All types do not require water-taps on both cylinders, but most receivers should be so drained. If an intercepting valve is used a reducing valve is not required, and if an intercepting valve is not used, there must be a valve to give independent exhaust direct to the atmosphere from the high-pressure cylinder. The weight of evidence, so far, is in favor of the use of an intermediate receiver. Such a device effectually isolates the cylinders, so that each retains its distinctive temperature. The general practice of drying the intermediate steam by putting the receiver in the smoke-box has much to recommend it. Copper pipes, set close to the curve of the smoke-box, are not cumbersome, or much in the way; and if it be desired that the feed-water also be heated in the smoke-box, the large receiver pipes need not interfere with the details of such an arrangement. Receiver capacity cannot, under our limiting conditions, be too large. It should never be less than 1½ times the volume of the high-pressure cylinder, and 2 or more volumes are desirable; because, with a liberal receiver, the steam supply to the low-pressure cylinder is more uniform in pressure and amount, the reheating or drying of the steam is more thoroughly done, and "the drop" in pressure between high-pressure final and low-pressure initial is less detrimental to steam economy.

If one side of a compound should break down, the other side can be run as a single cylinder engine, if the failure is not due to a total collapse of the cylinder on the side to be blocked. And in a tandem, as in a simple engine, the failure on one side may be a total collapse, without its interfering with the use of the other side as a single engine.

J. DAVIS BARNETT,
JOHN PLAYER,
H. D. GARRETT,
F. W. DEAN.

APPENDIX.

Size of cylinders for compound. M. V. Borries' rule for the large cylinder is:

$$d^2 = \frac{2\,Z\,D}{p\,h}$$

in which

d=diameter of the low-pressure cylinder, in inches.
D=diameter of the driving wheel, in inches.
p=mean effective steam pressure per square inch (after deducting internal machine friction).
h=stroke of piston, in inches.
Z=tractive force required, usually 0·14 to 0·16 of the adhesion (say 0·15, it being understood that allowance is made for the external engine friction, taken as equal to the whole friction of the cars).
The value of p depends upon the relative volumes of the two cylinders (or, if their strokes are equal, upon their comparative cross sections), and from experience and indicator experiments may be taken as follows:

Class of Engine.	Relative Section, or Ratio of Cylinders.	p in Per Cent. of Boiler Pressure.	p for a Boiler Pressure of 176 lbs.
		Per Cent.	Lbs.
Large tender engine..........	1:2 or 1:2·05	42	74
Tank engines......	1:2·15 or 1:2·2	40	71

For engines working long grades Z should = 0·16. And if the steam pressure is increased from 15 to 30 lbs., and the cut-off is to be 0·3 to 0·4 of the stroke in the small cylinder, the large cylinder may be 1·5 that of the cylinders of the ordinary simple locomotive for the same service. These figures are from M. V. Borries' publication in 1888, and. as Prof. Woods points out, are an increase in cylinder volume of about 7 per cent. on those given in 1886; whereas Mr. E. Worthington, in 1889, quotes M. V. Borries as recommending that the small cylinder be made the same size as one of the simple engine cylinders, and that the large cylinder should be twice the capacity of the small; boiler pressure being increased as before.

MR. E. WORTHINGTON'S RULE.

The following illustrates a plain method of calculating the size of cylinders in a compound to possess the same maximum power, at slow speed, as a simple engine:

Simple engine.—Boiler pressure 150 lbs.; two cylinders 17×24 in.; wheels, 72 in. diameter. The effective cylinder pressure will be c $\times$ boiler pressure; then—

Tractive power $= \frac{17^2\times24}{72}\times c\times150=14,450\times c.$

Compound engine.—Boiler pressure 180 lbs. Intermediate pressure 70 lbs., (difference 110 lbs.), stroke of cylinder as in simple engine, 24 in. Wheel 72 in. Let x represent the diameter of high pressure cylinder, then—Tractive power $=\frac{1}{2}\frac{x^2\times24}{72}\times c\times110+\frac{1}{2}\frac{2x^2\times24}{72}\times c\times70=x^2\times42c$; that is $14,450c=x^2\times42c$.

$x^2=\frac{14,450}{42}=344$; therefore $x=18\frac{1}{2}$ inches, or desired diameter of high-pressure cylinder; and $\sqrt{2\times18\cdot5^2}=26.1$ inches, or diameter of low-pressure cylinder.

He goes on to say that perhaps this method of estimating the diameters of compound cydinders may give slightly too large a result; for the average effective pressure in both may approximate nearer to the maximum effective pressure therein than in the simple engine, without running the risk of drawing fire through the tubes by a too violent blast.

M. Ch. Baudry, of the P. L. and M. Railway (Chemins de Fer de Paris a Lyons et a la Mediterranee), has given much attention to the compound, both as an investigator and experimenter; and his "note" on this subject is very interesting. A translation of his formulæ for relative cylinder diameters, and their cut-off ratios for varying speeds and pressures, will be found in the *Railroad Gazette*, March 7, 1890, pp. 161-2, or *National Car and Locomotive Builder*, May, 1890, pp. 75.

J. D. B.