Conference Paper

IMPROVEMENTS IN THE DESIGN, MAINTENANCE AND OPERATION OF THE MILWAUKEE RAILROAD ELECTRIFICATION

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IMPROVEMENTS IN THE DESIGN, MAINTENANCE AND OPERATION OF THE MILWAUKEE RAILROAD ELECTRIFICATION

LAURENCE WYLIE

On a warm afternoon in June, 1917 a bronzed chief of the Survey Party stood on a melting snow bank at the summit of the Cascade Mountains above Snoqualmie Tunnel in western Washington, and gazed intently through the telescope of his transit, watching his axemen and rodman far down the western slope in a tangle of huckleberry bushes and Devil's Club. Three years earlier and 800 miles to the east in eastern Montana they had started the survey of the Railroad's 100,000 volt power transmission line which was to serve power to the twenty two substations forming a part of the Electrification System of the Chicago, Milwaukee, St. Paul and Pacific Railroad. Two years and one war later the system would be completed, with the electric locomotives handling heavy freight and passenger trains through the valleys and canyons and up and over the summit of the five mountain ranges in the Northwestern states of Montana, Idaho and Washington. (See Fig. 1.)

The installation of the Electrification System was not the result of accidental and sudden decision or a by-product of depression or war. A plan to electrify the main line of the Milwaukee Road through the mountainous section from Harlowton, Montana to the West Coast was conceived during the years 1908 to 1912 simultaneously with the construction of the line of the Milwaukee from Mobridge, South Dakota to the Coast. At the same time the Railroad Company filed on power sites adjacent to the line of the Railroad, but later sold or relinquished their rights to these power sites as they did not care to go into the power distribution business and realized that over such an extended territory, and in view of the relatively low load factor of the proposed railway load, that they could purchase power from the established power companies at a lower cost than would be involved if the Railroad attempted to generate power solely for their own use.

The Electrification System, which was chosen after careful study, consists of a 100-KV three-phase power transmission line, power substations with transformers and motor generator sets for converting high voltage alternating current to direct current at 3,000 volts, a trolley distribution system to supply power to the electric passenger and freight locomotives, all of which were designed for regeneration of power and to operate on 3,000 volts direct current. This system was designed to handle a maximum of 2,800 tons in freight trains over the entire distance covered by the electrification. For nearly forty years this Electrification System has served the purpose for which it was installed, with constant and notable increase in tonnage and speed of trains.

This paper is considerably less than a profound engineering treatise and more of an explanation of the practical engineering steps which have been taken to increase the capacity and to reduce operating and maintenance costs to secure from this Electrification System results which are demanded by the ever-increasing tempo of Railroad operation.

In 1918 the schedule time for Train No. 16, the fastest passenger train between Avery and Harlowton was 15 hours. The present schedule for Train No. 16, the Olympian Hiawatha Speedliner, is ten hours and forty minutes.

In June, 1918 the schedule for Train No. 64, the eastward time freight between Avery and Harlowton with 2,800 tons trailing, which was the maximum tonnage at that time, was 36 hours, 45 minutes. Today with 5,800 tons the schedule for this time freight between Avery and Harlowton is 23 hours, 30 minutes, and the train is making this schedule. Not all of the saving in time is due to electrification, but the electrification system has been able to keep pace with changing times.

Passenger and freight train schedules and freight train tonnage on the Coast Division have been increased in like proportion.

100 KV POWER TRANSMISSION LINE

The Power Transmission Line between substations is owned, operated and maintained by the Railroad Company. This line consists of Western Red Cedar poles, fir cross arms, suspension disc insulators and 2/0 hemp core conductors, with a 3/8" SM steel ground wire. No treatment was applied to the poles prior to being set. During the years 1935 - 1938 creosoted fir stubs were placed on all poles. All of the wood guy anchors originally used were replaced with steel reinforced concrete disc anchors. 90% of the original poles and 70% of the original cross arms are still in place. No trouble is experienced with insulators. The hemp core in the 2/0 conductor is still firm and there is no fraying of this core due to Corona as was once anticipated.

One peculiar characteristic of this transmission line is almost entire freedom from trouble due to lightning, even though the line crosses the summit of five mountain ranges where lightning is both frequent and severe. This fortunate situation is apparently due to the use of wood poles and ground wire, and the additional shielding effect of the 3,000 V D.C. distribution network which parallels the transmission line and is, as far as lightning effect is concerned, a grounded system.

While some minor improvements in transmission line construction are made from time to time, the principal item of improvement is replacement of over-age poles, and replacement of doubtful cross arms with fir cross arms which have been given a five pound treatment of 5% Pentachlorophenol. When it is necessary to re-locate or rebuild sections of the transmission line adjacent to the right of way, combination trolley and transmission structures are used. (See Fig. 2.)

3,000 V. D.C. TROLLEY DISTRIBUTION SYSTEM

Except where steel structures are used at Butte, Renton, Seattle and Tacoma, Western Red Cedar poles are used as supporting structures for the trolley distribution system. Of the original poles used in the trolley system, about 85% are still in place. In the Bitter Root and Cascade Mountains, and between Cedar Falls and Seattle and Tacoma, Washington, where there is frequent precipitation, pole decay is accelerated, and it is in these sections where some pole replacements have been made.

Creosoted fir stubs were placed on all trolley poles and all wood guy anchors were replaced with steel reinforced concrete disc anchors in 1935 - 1938. There will be no deterioration of the concrete anchors with the passage of time, and it is estimated that there will be no appreciable deterioration of the treated fir stubs until the year 1970 or later.

Stranded steel cables in sizes from 1/4" to 5/8" are used for cross spans and guys. 1/2" steel strand is used for catenary wire supporting two 4/0 grooved copper trolley wires over main tracks and a single 4/0 trolley wire over sidings and yard tracks. In some yards and at other locations where climatic conditions and operation of steam locomotives under the trolley wire combine to produce a high rate of corrosion of steel cable, cable clips, and non-corrosive materials such as copper, Hi Tenso, and Calsun Bronze are used. We may find that with the elimination of steam operation, the use of galvanized steel in these sections will be satisfactory.

In order to compensate for voltage drop in the trolley distribution system due to a

100% increase in train tonnage as compared to tonnage for which the system was designed, additional feeder is being added in critical sections. 795,000 CM hard drawn aluminum (500,000 CM copper equivalent) is being used for this purpose as the cost of conductivity in aluminum at present prices is about one third the cost of copper.

By careful attention to trolley wire tension and alignment, and to pantograph maintenance, operating pressure and contact shoe lubrication, trolley wire wear is reduced to the point where replacement of trolley contact wire due to wear is negligible. The diameter of the new wire as installed is .482". The present average diameter of the trolley wire which was installed 35 to 40 years ago is approximately .440". The condemning limit for trolley wire account of wear is .382", indicating that the life expectancy of trolley wire on this system is indeterminable.

A notable change in trolley and transmission line construction, maintenance and repair methods has been made. The heavy gas electric rail cars with insulated hydraulic tower, and which cars required the use of an Engineer, Conductor and Brakeman, have been replaced by highway-type trucks and by road-rail trucks, and which latter type can operate with equal facility on either the highway or on rails. Line crews with these road-rail trucks perform all classes of work assigned to them, regardless of season, and with greater dispatch and at greatly reduced cost as compared to methods previously used. (See Fig. 3.)

MODERNIZATION OF SUBSTATION EQUIPMENT

There are 22 substations on the Milwaukee electrification for the purpose of converting the 110 KV, 3 Ø, 60 cycle power at the transmission line to 3400 V. D.C. power at the trolley bus. These stations are spaced from 21.8 to 41.6 miles apart. Two substations have one 2000 KW M.G. set each, 16 substations have two 2000 KW M.G. sets each, three substations have three 1500 KW M.G. sets each, and one substation has three 2000 KW M.G. sets.

The original design as to power requirements allowed one set at each substation as a spare in the event another set was inoperative. However, with the increase in train tonnage, it soon became necessary to use all sets at each substation to handle the heavier loads.

Among the many improvements that have been made in the substations to improve reliability, increase capacity, or reduce maintenance costs, are the following:

1. All the 115 KV electrolytic lightning arresters have been replaced by the Thyrite or autovalve type.

2. Surge equipment, consisting of a capacitor and station-type lightning arresters have been connected to the 2300 V windings of the synchronous motors of the M.G. sets.

3. All M.G. sets are now equipped with modern, high speed negative breakers to replace a negative breaker of an earlier design.

4. The 110 KV/2300 V. main transformers in all substations were modified to operate under nitrogen pressure.

5. Fifteen oil circuit breakers in the transmission line, having an interrupting capacity of 200,000 KVA, were replaced with modern 8 and 5 cycle breakers, having an interrupting rating of 1,000,000 and 1,500,000 KVA. Transmission line relaying has been changed and coordinated with the connecting power companies relaying by installation of modern phase to phase and ground relays.

6. At two substations, located on mountain grades where regeneration is heavy, regeneration absorbers were installed. Each installation consists of two units of 1380 KW capacity each, made from reconstructed diesel-electric locomotive dynamic braking units.

7. To increase the speed of trains the trolley voltage at substations was increased from 3000 volts nominal to 3400 volts. The increase in voltage was obtained by shimming back of the main field poles of the generators, thereby reducing the air gap and increasing the field flux.

8. Indicating disc-type thermometers have been applied to the direct current generators and maximum load is governed by commutation and temperature. The temperature sensing unit is imbedded in the iron of an interpole field, and which tests proved was a safe pilot for armature copper temperature.

9. Five of the substations have been automatized and plans call for automatizing others. Two of the substations are fully automatic, the starting of which is controlled by clock setting and low trolley voltage indication; the stopping is controlled by low power demand. The starting and stopping of M.G. sets at the other three automatic stations is under the control of operators, one of which resides at each of the substations about 38 miles apart. Each operator in turn, by means of supervisory control and telemetering, controls all three substations for an 8 hour period. The development and fabrication of equipment for automatizing the substation, like many other electrification improvements, was done with Railroad forces.

10. Two used 3000 KW M.G. sets in excellent condition, were recently purchased. One set is being installed on the Coast Division to replace a 2000 KW set that will be moved to another location. The second 3000 KW set will be installed on the Rocky Mountain Division where additional capacity is needed.

11. A systematic program of checking and recording insulation values has been inaugurated. Windings which have failed or on which high insulation values cannot be maintained are replaced with new coils.

Many minor, but very worthwhile improvements, such as carrier communication between substations and various protective devices have been installed in the substations. It can be stated that the substation portion of the electrification is keeping pace with the demands for increased capacity and reliable operation.

ELECTRIC LOCOMOTIVES

Characteristics of the various classes of electric road locomotives now in service are shown in Table 1.

Shop facilities have been improved and a modernization program has been in effect for several years for all locomotives requiring special attention. The following changes have been made or are in progress on all of the original General Electric geared freight units, which are operated as single units in heavy switching service, or as two, three, or four units in multiple for road service:

1. Replacement of the fused 3000 volt main power switches by quick acting circuit breakers.

2. Replacement of troublesome spring gears by solid gears. The spring gears were

composed of 56 individual parts per gear as compared to one single piece for the solid gears. (See Fig. 4, and Fig. 5.)

3. Additional shunting for traction motors to give more operating speeds and higher maximum speed. (See Table 2.)

4. Addition of permanent snow plow pilots.

5. Redesign of pantograph castings and springs and substitution of aluminum and magnesium castings in place of steel in order to reduce the weight and inertia of the pantographs. Roller bearings [illegible] [illegible] [illegible]

The five General Electric bipolar passenger locomotives have all been completely overhauled and the following improvements incorporated:

1. Modified streamlining. (See Fig. 6.)

2. Additional traction motor field shunting.

3. Redesign of the traction motor ventilating system.

4. Redesign of traction motor cutout arrangement.

5. Application of improved guiding truck restraint element.

6. Application of roller bearings to some units.

Five geared type passenger locomotive units were built from surplus freight units. (See Fig. 7.) These units are operated either as two unit or three unit locomotives. By taking advantage of the short time current rating of the traction motors in these units, they have a thirty minute capacity of 5,600 horsepower for two units, or 8,400 horsepower for three units. The thirty minute rating allows sufficient time for these locomotives to handle heavy trains up the heavy mountain grades, which are approximately twenty miles in length, without overheating of traction motors.

Figures shown in Table 3 indicate the excess capacity in traction motors of older design as compared to the direct current traction motors of modern design.

ELECTRIC POWER CONTRACTS AND COST OF POWER

Power for the Rocky Mountain Division Electrification System in Montana and Idaho is supplied by the Montana Power Company. Power for the electrification of the Coast Division in the state of Washington is supplied by Washington Water Power Company.

The original power contracts for the two separate districts were similar and specified payment for power delivered at 100 KV to the substation transformers at the rate of .536¢ per KWH, with minimum monthly payment based on 60% load factor, with billing demand determined by the contracts which were executed in advance of the actual operation, and which were later proven to be entirely too optimistic. The increase in traffic which was expected at the time these power contracts were drawn up did not materialize and a 60% load factor was considerably higher than obtained in actual operation, with resulting increase in actual cost per KWH as compared to estimated cost. A power indicating and limiting system was installed to totalize and limit the demand to any predetermined desired amount, but after several years use the operation of this limiting system was considered by the power companies and the Railroad to be unnecessary and use of this system was discontinued.

At various intervals during the 30 to 40 years covered by the two separate power contracts, revisions have been made in these contracts to provide terms more favorable to the Railroad Company and acceptable to the power companies. The last of such revisions were made in the Montana Power Company contract in 1950, and in the Washington Water Power contract in 1951. Under the terms of these revisions, power is metered at 2300 volts AC and the Railroad pays for power supplied at this voltage by the Montana Power Company at a flat rate of .536¢ per KWH, and for power supplied by the Washington Water Power Company a flat rate of .500¢ per KWH, plus a demand charge for peak load periods of 5:00 PM to 6:00 PM daily except Saturdays, Sundays and holidays, during the period of October 16th to February 15th inclusive. Application of the terms of the Washington Water Power contract produces an annual average rate per KWH only slightly higher than the flat rate of .536¢ specified by the Montana Power contract.

GENERAL

In making a comparison of motive power for railroad transportation the answer can usually be found in analysis of a limited number of the principal components, i.e.;

(1) Adequacy of the system.
(2) Cost of operation, including
  (a) Fuel vs electric power (where cost of electric power includes a cost incidental to supplying power at and to the locomotive).
  (b) Cost of locomotive repairs.
  (c) Fixed charges on investment (including interest, taxes and depreciation).

Due to the age of the Electrification System now under discussion, the item (fixed charges on the investment) can be eliminated, with resulting operating costs as shown in Table 4, by years for the period 1947 to 1954 inclusive.

No substantial comparison can be made of these figures with the figures from another system unless that system also operates through mountainous territory, including heavy grades, heavy curves, and other natural barriers which serve to restrict speed, increase power or fuel consumption, and impose gruelling loads on motive power.

CONCLUSIONS

Age is not a suitable criterion of the efficiency, adequacy, or economy of electrical or mechanical installations. In the case of the C. M. St. P. & P. Railroad electrification, the efficiency, reliability and capacity of the power transmission system, substation transforming and converting equipment, trolley distribution system, and electric locomotives, will stand the test of comparison with equipment of current design. All components of this system except power substation buildings have now exceeded by many years the original life assumed for purposes of amortization. The net salvage value of the system is relatively low.

The present satisfactory performance and comparatively low cost of operation do not warrant expenditure of the large investment required for replacement with a different type of electrification system, or replacement with a different type of motive power.

It is recognized that time will bring about some decided changes in, or abandonment of, the present Electrification System, but there is now no clear indication of what this change will be or when it will take place.

TABLE I

WEIGHT – TRACTIVE EFFORT – HORSEPOWER AND SPEED

ELECTRIC ROAD LOCOMOTIVES USED BY THE C.M. St. P. & P. R.R. CO.

CLASS	TOTAL WEIGHT POUNDS	WEIGHT ON DRIVERS POUNDS	TRACTIVE EFFORT # 18% ADH.	TRACTION MOTOR AMPS		TRACTIVE EFFORT -#		HORSEPOWER		SPEED - MPH		
				CONT.	HOURLY	CONT.	HOURLY	CONT.	HOURLY	CONT.	HOURLY	MAX.
EF-1	576,000	451,000	80,800	230	285	80,000	106,000	3340	4100	15.5	14.5	45
EF-2	864,000	676,500	122,000	230	285	121,200	159,000	5010	6150	15.5	14.5	45
EF-3	816,000	691,000	124,500	230	285	121,200	159,000	5010	6150	15.5	14.5	45
EF-4	586,800	435,400	78,300	345	375	77,000	85,500	5110	5530	25.2	24.5	65
EF-5	1,056,000	931,000	168,000	230	285	161,600	212,000	6680	8200	15.5	14.5	45
EP-1	658,500	523,500	94,100	230	285	43,100	60,000	3340	4100	29.0	26.5	75
EP-2	521,200	457,800	82,200	222	247	42,000	48,500	3180	3517	28.4	27.1	70
EP-3	620,000	420,000	75,700	315	390	49,000	66,000	3400	4200	26.0	23.8	70
EP-4	578,350	432,100	77,800	345	375	77,000	85,000	5110	5530	25.2	24.5	70

TABLE II

INCREASE IN TRACTION MOTOR FIELD SHUNTING

TRACTION MOTORS	SERVICE	% FIELD STRENGTH AS RECEIVED FROM MANUFACTURER	% FIELD STRENGTH AS NOW OPERATED
GE #253	Freight	100 – 47	100–73–54–40
GE #253	Passenger	100 – 47	100–75–54–40
GE #750	"	100–74–54	100–56–38
GE #100	"	100 – 50	100–65–50–40
WH #348	"	100–86–72	100–65–35

TABLE III

COMPARISON OF TIME - CURRENT RATINGS FOR HIGH VOLTAGE DIRECT CURRENT TRACTION MOTORS OF ORIGINAL VS MODERN DESIGN

Traction Motor No.	Voltage Per Motor	Year Placed in Service	Type of Locomotive	Current Rating Expressed in Per Cent Continuous	90 Min.	60 Min.	30 Min.
A	1500	1915	Electric	100	119	138	171
B	1000	1919	"	100	117	139	169
C	1500	1919	"	100	110	119	133
D	1500	1949	"	100	104	109	113
E	1000	1952	Diesel	100	101	102	107
F	1000	1954	"	100	103	105	112

TABLE IV

COST PER 1000 GROSS TON MILES FOR ELECTRIC POWER AND ELECTRIC LOCOMOTIVE MAINTENANCE FOR FREIGHT TRAIN OPERATION

ROCKY MOUNTAIN AND COAST DIVISIONS: C. M. St. P. & P. RR Co.
1947 to 1954 (Incl.)

STATISTICS:	1947	1948	1949	1950	1951	1952	1953	1954
MGTM	3,296,459	3,354,933	3,193,389	3,520,283	3,416,041	3,363,201	3,159,959	3,141,928
KWH per MGTM - 2300 V A.C.	36.9	37.6	37.1	37.7	39.9	40.0	39.0	37.4
COST PER KWH - 2300 V A.C.								
Electric Power	$.006422	$.006392	$.006435	$.005940	$.005470	$.005390	$.005380	$.005400 ✓
Substation - Operation	.001600	.001660	.001837	.001832	.001819	.001950	.002020	.002013
Substation - Maintenance	.000511	.000389	.000411	.000398	.000590	.000543	.000695	.000462
Power Line - Maintenance	.000914	.000933	.001147	.000833	.000945	.001186	.001164	.001130
TOTAL	$.009447	$.009374	$.009830	$.009003	$.008824	$.009069	$.009279	$.009005
COST PER MGTM								
Power Charges	$.3486	$.3525	$.3647	$.3394	$.3521	$.3628	$.3619	$.3368
Locomotive Repairs	.1637	.1885	.1937	.2229	.2628	.3281	.3559	.3015
TOTAL	$.5123	$.5410	$.5584	$.5623	$.6149	$.6909	$.7178	$.6383

1 - Gal Diesel fuel = 10 KWH.
10¢ per gal = 1.0¢ per KWH

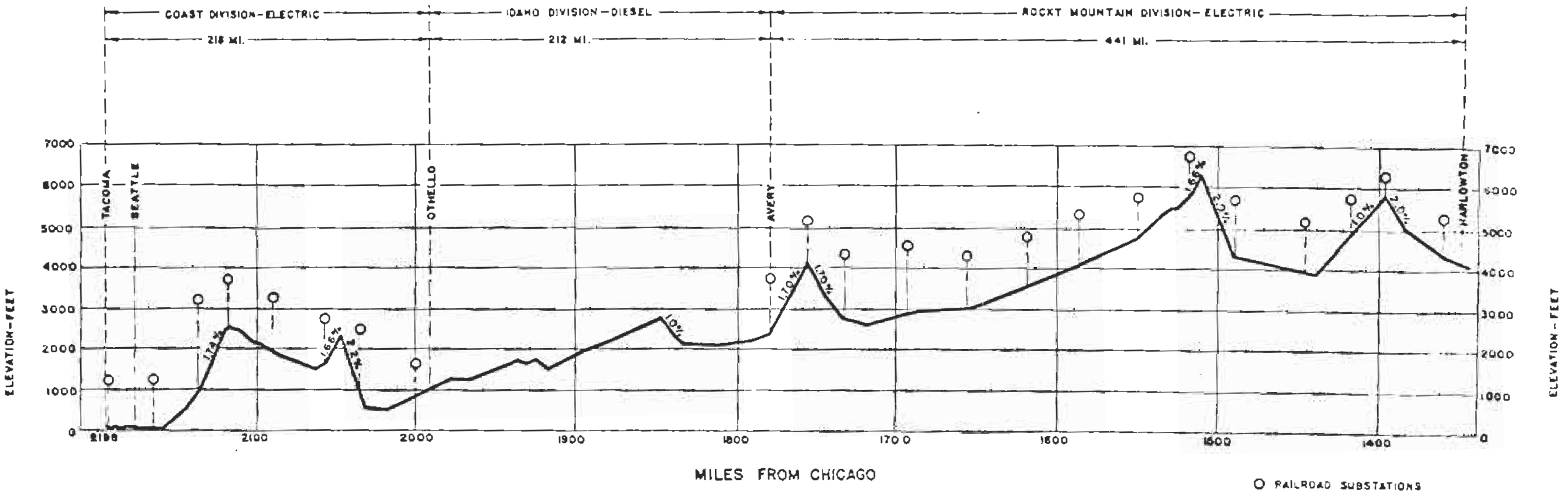

Fig. 1. Profile of C.M.St. P. & P. RR
Harlowton, Mont., to Tacoma, Washington

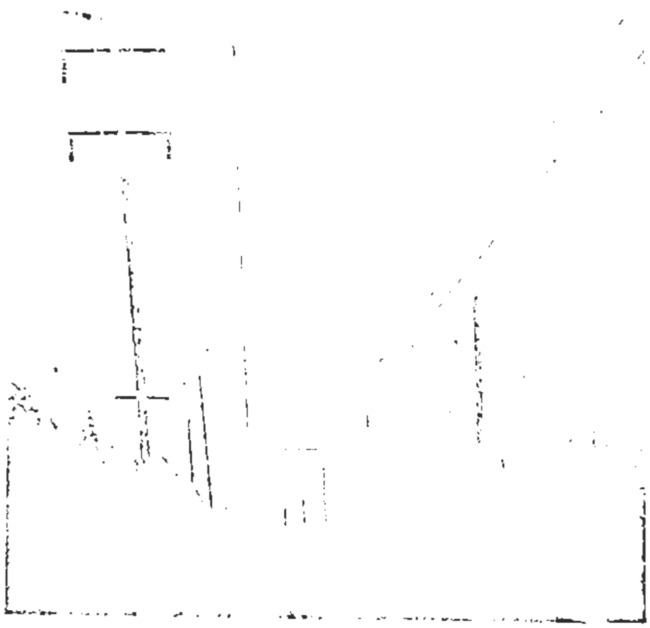

Fig. 2. Combination construction, Trolley and Transmission System.

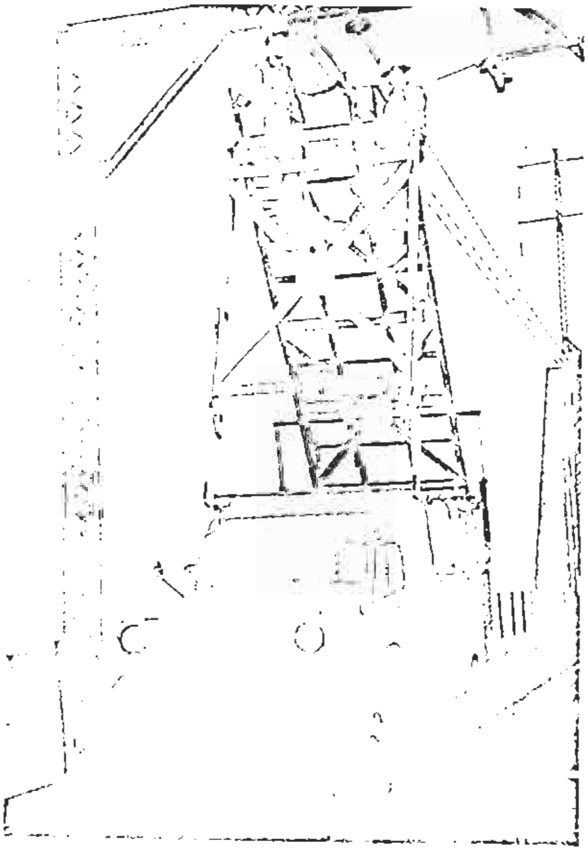

Fig. 3. Electrification Department - Road-Rail Truck.

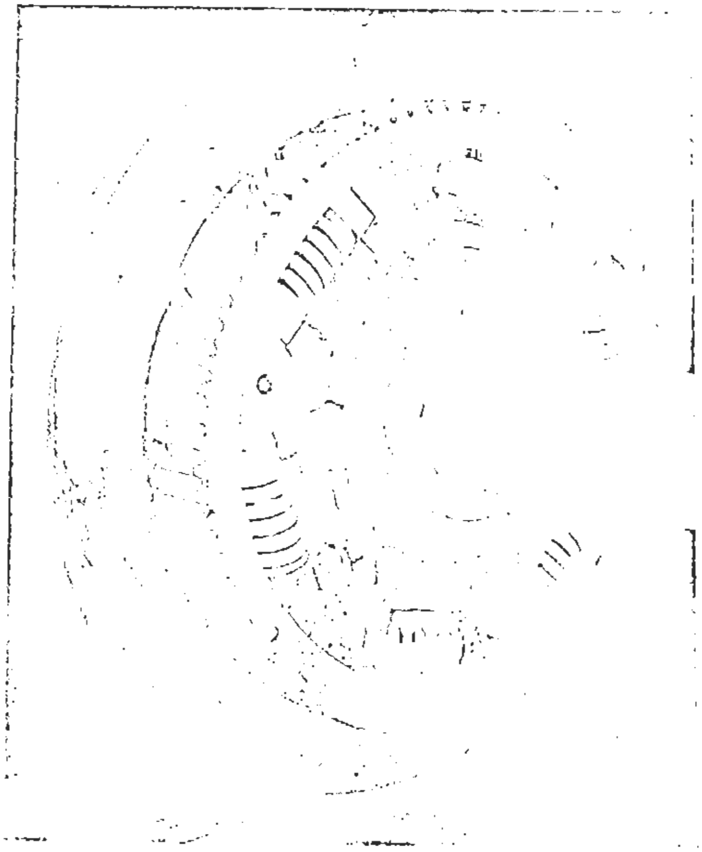

Fig. 4. Spring gear - composed of 56 separate parts.

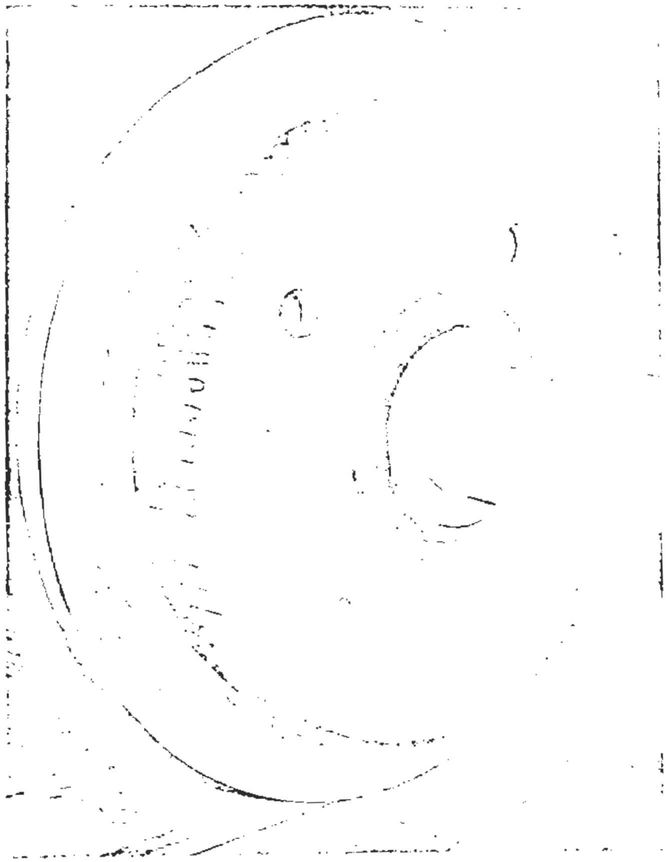

Fig. 5. Solid gear - one piece.

Fig. 6. Modernized bipolar passenger locomotive. (Now working in the 2,000,000 mile class.)

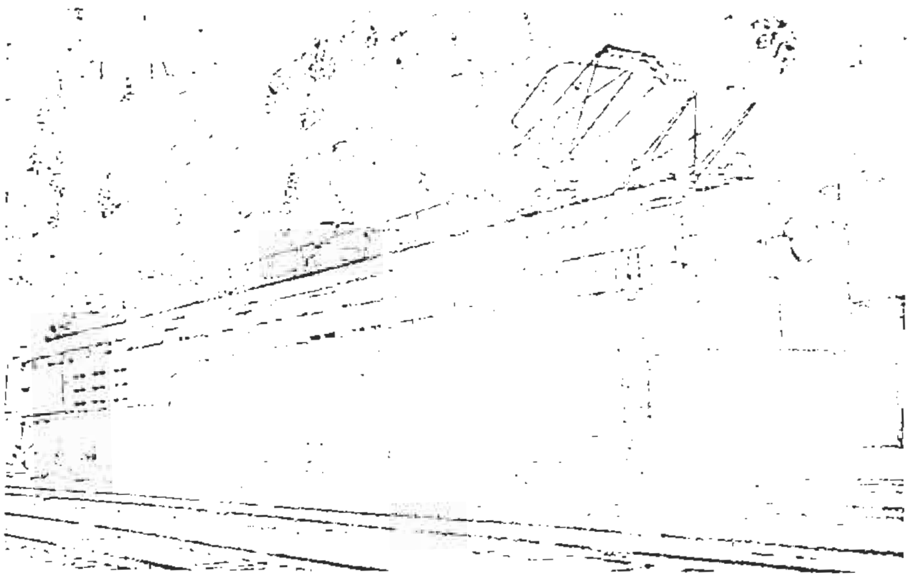

Fig. 7. Two-unit geared passenger locomotive, rebuilt from surplus freight units.