Report L-240
15 July 1922

MEMORANDUM OF SYSTEMS OF TRANSFER OF RAILWAY MOTORS FROM SERIES TO PARALLEL.

When deciding upon the system of transfer to be used in re-arranging the motor groupings on a locomotive or car, there are a certain number of general requirements for all types of control for both locomotives and cars, and in addition there are a number of points determined by the specific requirements of each case that must be considered.

GENERAL REQUIREMENTS.

1. The transfer should be made without shock to the train or car.

2. In order to be able to accelerate up to full capacity of the locomotive, the parallel circuits should be balanced after the transfer is made. This is very important in locomotive service, as acceleration is generally required up to slipping point of the wheels. For cars where there is either no trailing weight or else very little compared to a locomotive, this is not so important as the service generally does not require acceleration up to slipping point of the wheels. For this reason one type of transfer may be satisfactory on cars and not on locomotives.

3. Economy of apparatus or the complications involved, must be considered for each specific case.

4. The transfer must be accomplished without injury to apparatus or undue wear and tear on equipment.

SPECIFIC REQUIREMENTS.

1. Where it is advantageous to keep the fields always on the ground side in order to reduce the size of the motors, the system of transfer should permit this and still fulfill the four general requirements.

2. Where regeneration is used it is generally necessary for economical reasons to group all the fields on the ground side particularly in order to reduce the number of exciters and to allow low voltage insulation. The system of transfer should permit this and still fulfill the four general requirements.

TRANSFERS.

"L" TRANSFER (OPEN CIRCUIT METHOD).

In this system all the motors are disconnected from the line and the transfer is made with no current on the motors. This system was the first method used on cars but its use was discontinued as it was not as satisfactory as a transfer which maintains all or a portion of the torque. It does not fulfill general requirement number 1.

"K" TRANSFER (SHORT CIRCUIT METHOD).

In "K" transfer one group of motors is short circuited and disconnedted from the line and then connected in parallel with the other group. Fig. 1 shows the various steps of transition.

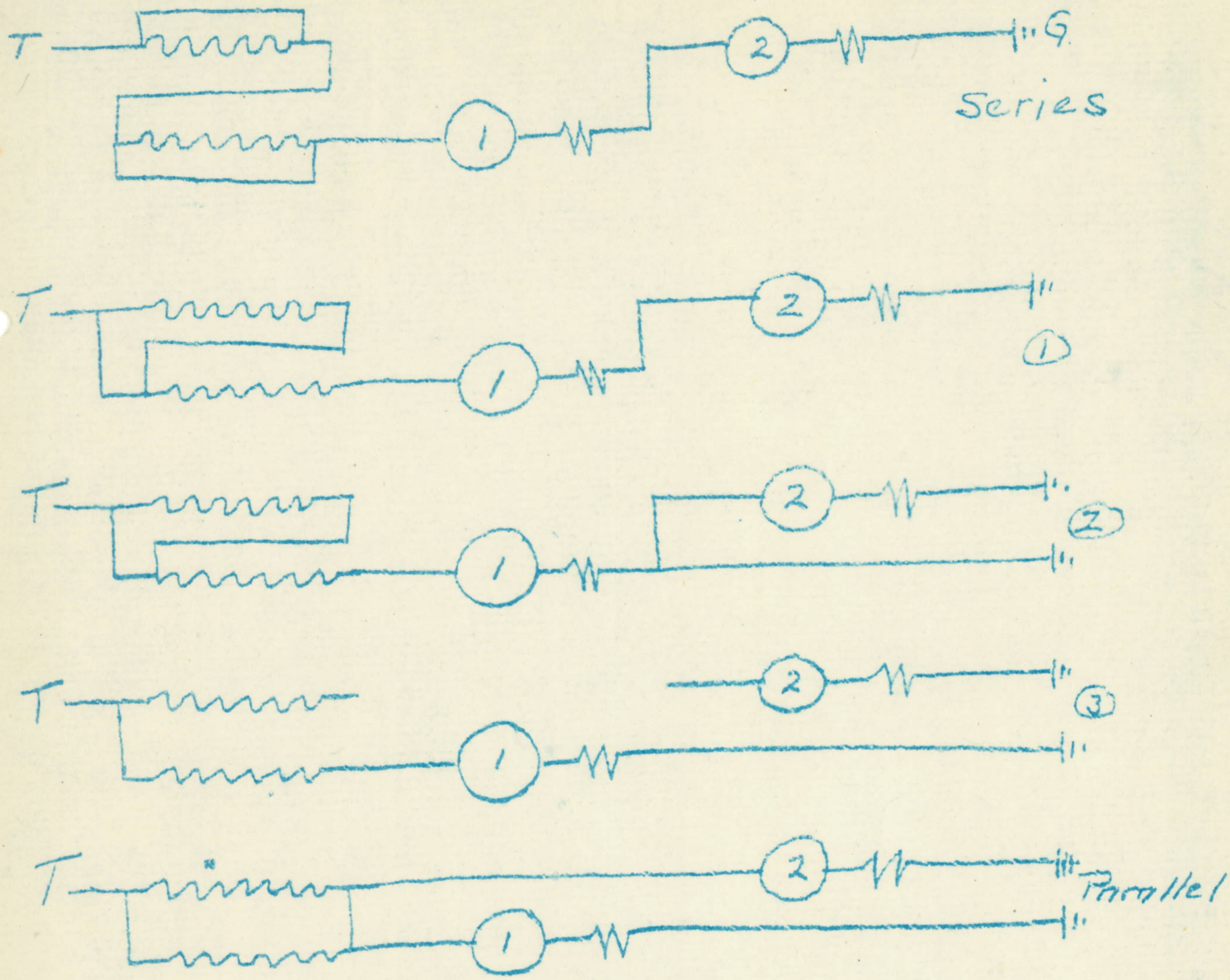

Fig. 1.

With this method the torque fails momentarily to about half the initial torque after the resistance has been re-inserted and remains there while the motors are shorted if the proper amount of resistance has been used. The effect of this dip in torque on the train or car is entirely a function of the duration. It has been found that when the transfer occurs in a small fraction of a second, this dip in torque produces no appreciable shock or surges, due to the inertia of the train. The maintained torque is sufficient to keep the draw bar springs in tension and there is, therefore, no tendency for the springs to cause a surge in the train. Years of exceptionally heavy service on the Butte, Anaconda and Pacific Rwy. and C.M.& St.P. Railway has shown that this system is entirely satisfactory from the view-point of its effect on the train.

As all the accelerating resistance is connected on the same side of the motors they can be paralleled so that in the parallel connection equal voltage is applied to all circuits, thereby leading all motors equally, regardless of variations in the accelerating resistances.

Experience has shown that the transition contactors suffer very little burning. The contactors which open the shorted motor circuit open only a low voltage since the motor voltage is killed by its own field after it is short circuited. It is sometimes necessary with high speed motors to shunt the motors with a resistance instead of short circuiting them, in order to protect the motors better during the transfer at high speeds.

For specific cases where fields are required to be grouped on the ground side this system of transfer offers no difficulties as the armature of the shorted motors may always be connected with their fields on the low side and the resistances may be always connected ahead of the fields.

"T" TRANSFER (SHUNT CIRCUIT METHOD).

"T" transfer or transition by means of shunting motors through resistance is somewhat similar to "K" transfer except that instead of shorting the motors directly, they are shorted by part of the accelerating resistance. As shown in Fig. 2.below, the first step is to shunt a resistance across part of the motors, at the same time leaving full potential across the motors connected in series.

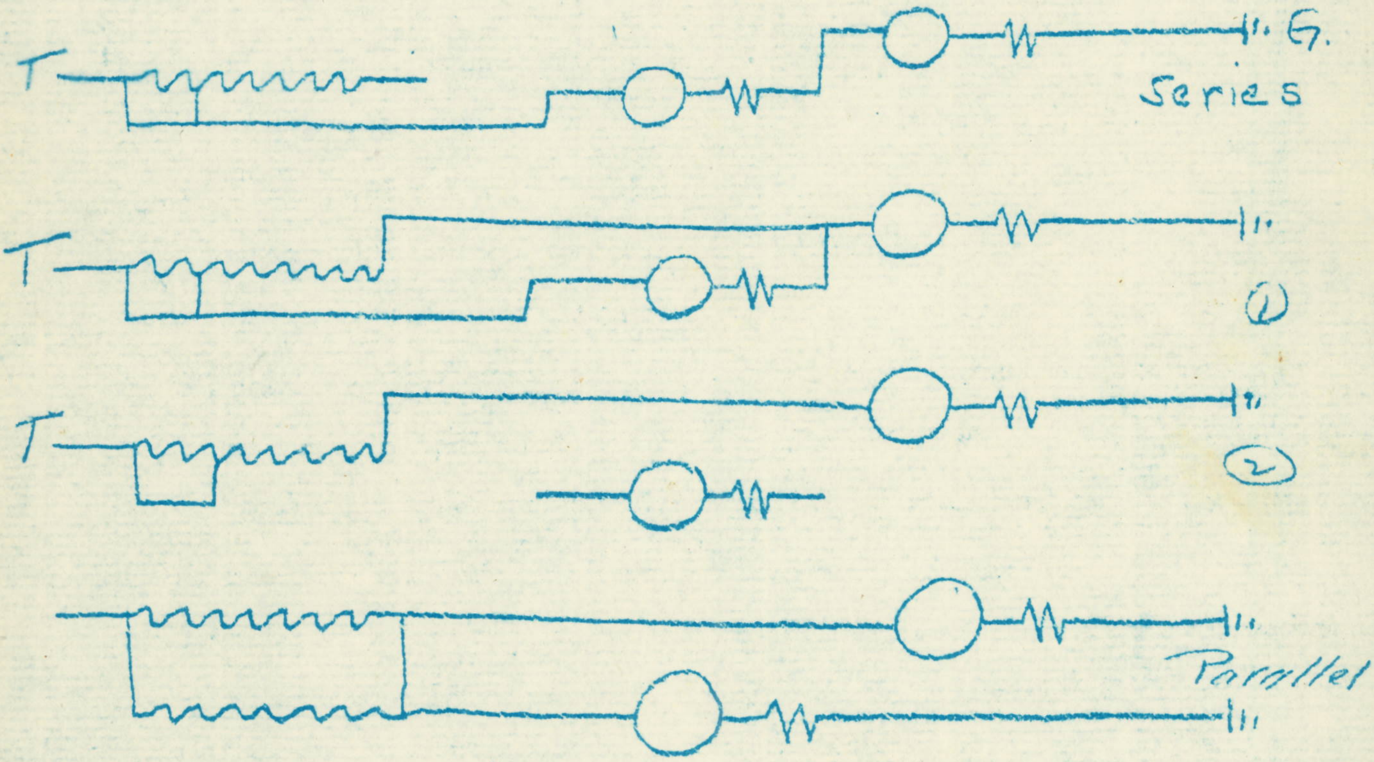

Fig. 2.

Resistance is not cut in prior to shunting the motors which gives one less step of transition than with "K" transfer. Part of the motors are disconnected from the circuit and reconnected in parallel as in "K" which drops the torque down to about one half, momentarily. For reasons already explained this procedure is entirely satisfactory from the point of view of its effect on the train, when the transfer is accomplished in a fraction of a second.

As this transfer permits connecting all accelerating resistances on the same side of the motors, the resistances can be paralleled so that the circuits are balanced after transfer.

As the resistors may be paralleled, the accelerating contactors may be used economically to give a maximum number of steps.

There is nothing inherent in "T" transfer which would cause undue burning on the transition contactors. In general there is less arcing on the transition contactors than with either "K" or bridge transfer.

For regenerative locomotives where fields must be grounded on the low side, "T" transfer cannot be used without increasing the number of accelerating contactors. The reason for this is that the connection naturally lends itself to shunting the motor on the high side of the circuit, and that the field must be included with the armature when it is shunted.

BRIDGE TRANSFER.

The various steps of bridge transfer are shown in Fig. 3. The principle is that of the Wheatstone Bridge with the transition contactor connected across the middle point.

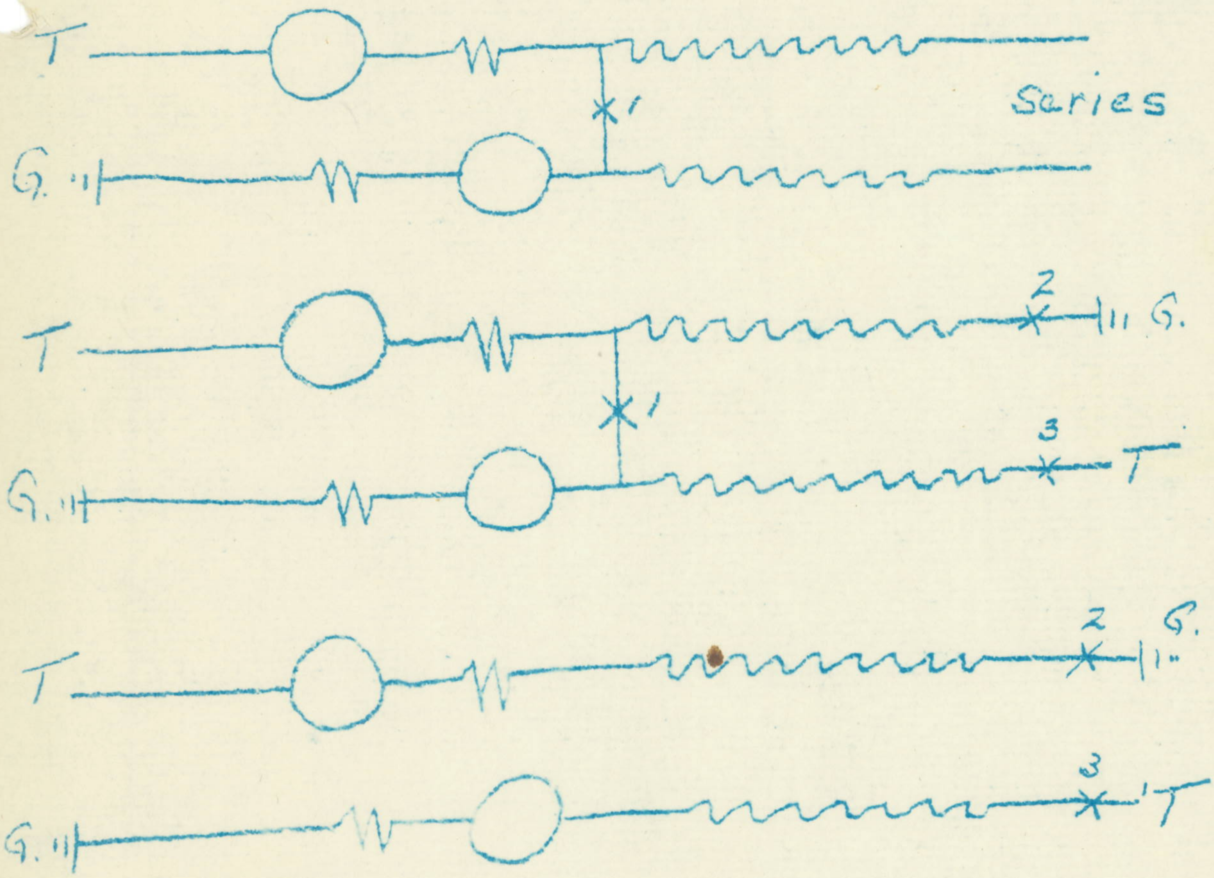

Fig. 3.

If transfer is made at a value of current equal to the current flowing through the accelerating resistance, there is theoretically no change of torque. However, if the transfer is made at a higher or lower current there is respectively a decrease or increase in torque. Accelerating up to 30 percent on drivers, a decrease of 33 percent of torque is unprobable in a normal layout of resistance, due to the unbalancing of the bridge alone. In addition to this there is a further decrease in torque due to increased line drop when the resistances are connected across the line. As stated under the discussion of "K" transfer, if the transfer is rapid the dip in torque is absorbed by the inertia. Bridge transfer is entirely satisfactory from the point of view of shock to thetrain.

This transfer requires resistances on the low and high side of alternate circuits in parallel. It is impossible to parallel resistors connected to the line with resistors connected to ground, so that even if the independent parallel circuits are laid out so as to cut out simultaneously in each circuit equal resistances at each accelerating step (which we consider very necessary for locomotive acceleration), the voltage is not necessarily equally divided between the independent circuits. Unbalancing may result from any or all of the following: (1) Unequal heating of individual resistors caused by series acceleration. (2) Variation in manufacture. (3) Variation in contact resistance between grids.

It is possible for the combination of these causes to give a variation of 25 percent or more in the resistance of the parallel circuits. From actual calculations a variation of 25 percent will cause unbalancing between parallel motors up to about 25 perdent in torque. The second general requirement for locomotives is therefore, not fulfilled.

From the point of view of economy of apparatus this system has the inherent disadvantage of requiring resistances connected to the line and to ground in alternate parallel circuits. This means that the resistances cannot be paralleled. In order to even approximately balance the load between motors, equal resistances must be cut out of each separate parallel circuit at each accelerating step. Therefore, if a certain number of accelerating steps are required, sufficient contactors to obtain these steps are required in each resistor circuit or group of circuits not paralleled. If resistor circuits could be paralleled as in "K" or "T" transfer, contactors could be closed alternately in the different resistor circuits thereby obtaining the required steps with less contactors than are necessary with bridge transfer.

From the standpoint of maintenance of apparatus, bridge transfer operates satisfactorily. There is one point, however, which, experience has shown, causes the transition contactors to burn more than might be expected. If transferring below the theoretical bridge current, the current through contactor #1 is reversed when 2 and 3 close and immediately #1 must open. If the flux in the blowout has not had time to build up in the reverse direction the contactor opens with little or no blowout flux and the result is more than the ordinary burning.

We know of no economical way at present of fulfilling the specific requirements of keeping the fields grouped on the low side with bridge transfer, when this is necessary for regeneration or for economy in motor designs.

COMPARISON.

"K" Transfer.	"T" Transfer.	Bridge.
		Least change in torque on transfer.

No noticeable difference in effect on train during transfer, due to short duration and due to maintaining sufficient torque to keep springs in tension.

"K" Transfer.	"T" Transfer.	Bridge.
Parallel circuits balanced. Full accelerating capacity.	Parallel circuits balanced; Full accelerating capacity.	Parallel circuits may be considerably unbalanced, resulting in less accelerating capacity.
About same amount of apparatus as "T".	About same amount of apparatus as "K".	Greatest number of contactors necessary for acceleration.
It may at times be necessary to add a transfer resistance to protect the motors during transfer.	No injury to motors.	No injury to motors.
Simplest method when necessary to keep fields on ground side for regeneration and low voltage fields.	Not adapted for grouping fields on low side for regeneration without added complications.	Not adapted for grouping fields or connecting them on low side. With regeneration means multiplicity of exciters with high voltage insulation.

SUMMARY.

Summarizing the above comparison, the reasons for the choice of either "K" or "T" transfer in preference to bridge may be stated as follows. While bridge has the theoretical advantage of less torque change during transfer, in actual practice there is no operating difference between the three methods on the basis of shock to the train. All are equally satisfactory. Bridge transfer requires more apparatus and allows a probable unbalancing of motor loads (reducing the accelerating capacity of the locomotive), without having any advantage from an operating point of view.

For locomotives, "T" transfer is generally used in preference to "K", except when regeneration is used or when it is advantageous to keep the fields at low potential for economy in motor design. For these specific cases "K" transfer is the most economical in use of apparatus and the motors may either be short circuited on transfer, or shunted through a transfer resistance.

For car equipments where it is hardly ever necessary to group the fields on the ground side, "T" transfer has some advantage over "K" as it requires one less step during transition. "T" is therefore, now more generally used on cars than "K" transfer.

P. W. Forsberg,

RAILWAY EQUIPMENT ENGINEERING DEPARTMENT.

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