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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

TRIAL REPORT ON ADHESION IMPROVEMENT OF WAG9 LOCOMOTIVES

Report No. RDSO/2013/EL/IR/0162, Rev.0

Approved by	Signature
Sr. EDSE	(signed)

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1.0 Background:

When the tractive force produced by a locomotive exceeds the limit of adhesion, wheel slip occurs, dissipating the extra energy as heat. The maximum deliverable tractive force in any locomotive is the product of the adhesive weight and co-efficient of adhesion. Due to track stress considerations, maximum adhesive weight under static conditions is fixed (example 123t in case of WAG-9). During motion of the train, however, the adhesive weight also dynamically changes due to vertical and lateral oscillations, curves, gradients etc. The coefficient of adhesion on the other hand also varies very widely depending upon the track and weather conditions. Due to these considerations, to get maximum possible tractive force within the above-mentioned constraints, it is a practice worldwide to provide an adhesion control system integral to the drive control. However, due to inherent problem of calculating reference speed out of actual speeds of all axles, there is always possibility of calculation of wrong reference speed. Due to this and with group drive operation, the adhesion performance of the WAG9 locomotive has not been quite satisfactory under adverse weather conditions. There have been many cases of stalling while hauling standard loads during rainy and adverse weather conditions. The existing traction control in three phase locomotives can be explained with the help of following block diagram:

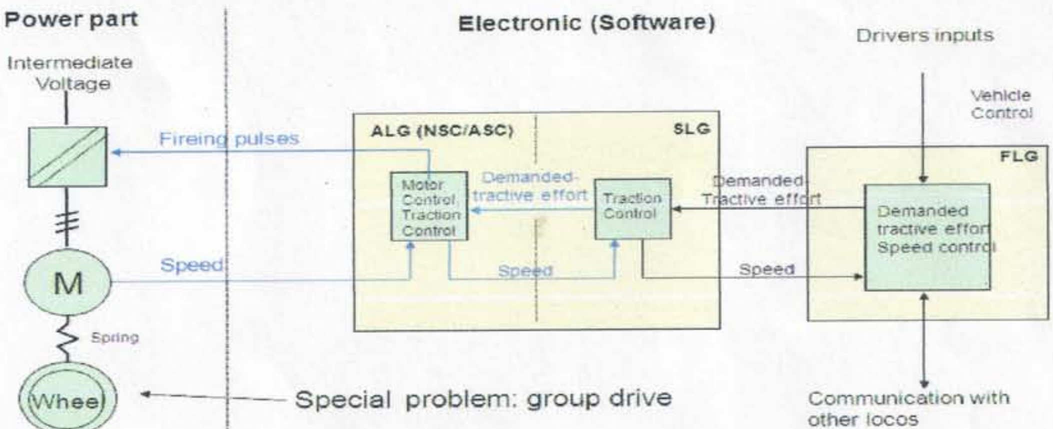

Fig.1

Originally, Wiegand type speed sensors (a patented technology using a special wire – Wiegand wire & magnetic circuit) have been provided on each traction motor for measuring the rotating speed of motors. Trials conducted in the locomotives in service revealed that the reliability of wiegand sensors is not satisfactory. The output pulses are very weak and are highly susceptible to air gap accuracy. A slight change in the air gap may cause either missing pulses or total absence of pulses. The sensor being passive (working on Wiegand principle), there is no chance of directly increasing the output pulse strength and hence Weigand speed sensor, does not give exact speed output due to missing pulses. The lower speed indicated by some or all of the speed sensors further try to reduce the tractive effort reference by mistakenly arriving at a slip condition.

In order to eliminate the problems of Wiegand speed sensors, active speed sensors based on Hall Effect principle was developed and so far more than 2500 Nos. Hall effect based speed sensors have been fitted in locomotives and are under operation on I.R.

In view of above reasons, Zonal Railways have been reporting poor adhesion of WAG9 locomotives specially during rainy season. In order to eliminate the above problem, limited quantity of Doppler Radar along with Hall effect based speed sensors with modified adhesion logic have been provided on locomotives for adhesion improvement.

While conducting the field trials to judge the performance of Doppler radar based adhesion control system and from the data analysis of the plots obtained from Doppler Radar based adhesion control and the existing control system of MICAS, considerable reduction in the TE demand transferred to ASC was observed during slip conditions. The reduction varies between 25% in normal slip conditions to 60% in heavy slip conditions causing stalling of loads. Further analysis of trials showed that the demand transferred to ASC is varying directly to factor ZBKRFkt1 of SLG (FG 9056). This indicates that the factor ZBKRFkt1 influences the demand transferred to ASC in direct proportion.

The detailed analysis and graphical plots have been given in Appreciation Report on Doppler radar based slip slide control system submitted to Railway Board vide RDSO letter No. EL/3.1.35/26 dated 10-4-13.

2.0 Trials with M/s BT/Switzerland:

Based on the conclusion and recommendations made in the Appreciation Report, it was further decided to investigate this further with the help of M/s BT as this factor could be responsible for poor adhesion of the locomotives. Joint trials were further conducted by RDSO with representatives of M/s BT/Switzerland from 14-4-13 to 16-4-13 with ECR and CLW. Before conducting the trials, a presentation was also made by BT/Switzerland representative at ELS/GMO. During the presentation, M/s BT/S has explained the logic of adhesion control and various factors affecting the slip slide control as per following diagram.

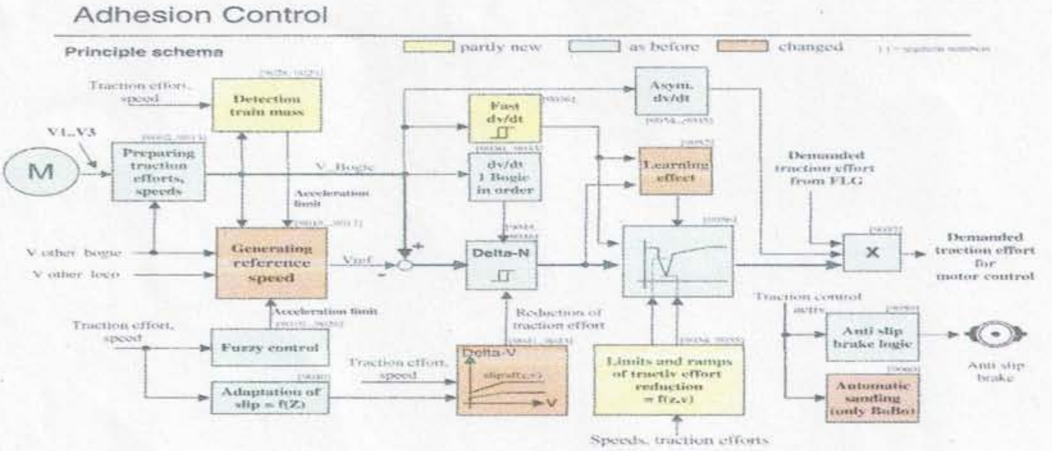

Fig.2

M/s BT/S also explained that the above adhesion logic is adopted worldwide and any change in basic logic is not possible. They also opined that any modification in rate of change of TE transferred to ASC by SLG has to be done very carefully keeping the mechanical considerations in mind.

Based on the trials conducted from 14-4-13 to 16-4-13, M/s BT/S modified the software for following:

- Parameter PA90_P9017-VRef-UG = -4.00% instead of 0.00%.(This parameter has been added to control the slip while loco starts trailing due to gradient.)
- Parameter PA90_P9051A-TupLem = 500G (This parameter is added to reduce the slope of critical factor ZBKRFkt1 so that reduction in TE is gradual and not abrupt. Earlier this parameter was 300G).
- Auto sanding functionality added to automatically activating sanding. Auto-sanding shall be activated in below condition:

  - demanded tractive effort of bogie must be > 100kN
  - learning effect is lower than 90%
  - Train acceleration is lower than 0.08ms-2
  - Speed is lower than 40-50Km/h

- Test Parameter is implemented to activate Sanding functionality.

Based on above, further Joint trials were done by RDSO with ECR, CLW & M/s BTIL from 13-6-13 to 15-6-13 as per the test cases given by M/s BT/S with modified software. The data recorded were sent to M/s BTIL for further analysis and were also analysed by RDSO. Based on these trials, M/s BTIL further improved the adhesion control logic for optimized auto sanding as detailed below:

- **Additional logic for control auto sanding (9060-AUTOSAN-DG1)**
  - → Function block 8-11 are added.
  - → Function for block 8-10 is, When actual tractive effort is > 400 kN for 10 s the automatic sanding will be disabled.
  - → Function for block 11 is, When Demanded tractive effort of bogie is high (i.e. 4606-WAZBK-A1 > 210 kN), the auto-sanding will be disabled.

Based on the analysis of trial results, RDSO advised CLW to issue modified software to ECR, CR, SECR and SCR to download the software in five locomotives each and monitor the performance to gain more experience. There is no adverse report from Zonal Railways wherein this software has been down loaded.

3.0 Joint Trials by CLW, ECR and RDSO:

It was further decided to conduct trials to monitor the improvement as a result of above modifications in adhesion control system and accordingly joint trials were done on 30-7-13 and 31-7-13 in ECR by downloading modified software in Loco No.31001 and with existing software in Loco No. 31044.

The details of trials conducted on 30-7-13 are as follows. Following signals were monitored using MICVIEW.

S. No	Name of Signal	Description
1.	SLG1 FLG1_G 46-WTE/BE-B1	Demanded Tractive Effort per bogie from FLG
2.	SLG1 FLG2_G 46-WTE/BE-B1	,,
3.	SLG1 SLG1_G 0416*WAZBKRg1	Demanded Tractive Effort per bogie to ASC, included learning effect;
4.	SLG2 SLG2_G 0416*WAZBKRg1	,,
5.	SLG1 90--_G 9060-BSandValv	Signal for auto sanding activation monitoring
6.	SLG1 90--_G 9011XVist-A1	Speed axle-1_Bogie-1
7.	SLG1 90--_G 9011XVist-A2	Speed axle-1_Bogie-1
8.	SLG1 90--_G 9011XVist-A3	Speed axle-1_Bogie-1
9.	SLG1 SLG1_G 90-Xspeed	Bogie speed
10.	SLG1 90--_G 9011-XVist-DG1	Internal signal of axle speed Bg1

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S. No	Name of Signal	Description
11.	SLG2 90--_G 9011-XVist-DG2	Internal signal of axle speed Bg2
12.	SLG1 90--_G 9017-XVrefFilt	Filtered speed
13.	SLG1 90--_G 9066-ZBKRFkt1DG1	Critical factor when slip occurs Bogie-1
14.	SLG2 90--_G 9066-ZBKRFkt1DG2	Critical factor when slip occurs Bogie-1
15.	SLG1 90--_G 9035-ZBKRdvdtDG1	dv/dt factor during slip
16.	SLG2 90--_G 9035-ZBKRdvdtDG2	dv/dt factor during slip
17.	SLG2 90--_G 9017-XVrefFilt	Filtered speed Bogie-2
18.	SLG2 90--_G 9011XVist-A1	Speed axle-1_Bogie-2
19.	SLG2 90--_G 9011XVist-A2	Speed axle-1_Bogie-2
20.	SLG2 90--_G 9011XVist-A3	Speed axle-1_Bogie-2
21.	SLG2 08--_G 0875-WARedBglsp	LSP indication
22.	SLG1 SLG1_G 90-XTE/BE	Actual TE/BE Bogie-1
23.	SLG1 SLG2_G 90-XTE/BE	Actual TE/BE Bogie-2
24.	SLG1 91--_G 9052-WAZBKR-DG1	Internal signals
25.	SLG2 91--_G 9106-WAZBKR-DG2	Internal signals
26.	SLG1 91--_G 9106-WAZBK-DG1	Internal signals
27.	SLG2 91--_G 9106-WAZBK-DG2	Internal signals

Table-1

The details of trial with modified software are shown below:

With modified Software for adhesion improvement loaded	
Section	Gomoh to Kodarma
Date	30-7-2013
Locomotive Number	WAG9 - 31001

Departure (GMO)	13:40 Hrs
Arrival (Kodarma)	15:40 Hrs
Driver	Shri B.N.Dey
Assistant Driver	Shri D.Mistry
Trailing Load	59 BOXN + 1MT
Total Load	5040 Tones
Banking	NIL
Weather	Clear and Dry
Accompanied by	Mr. V. K. Singh, Dy Dir/RDSO Mr. A. K. Sharma (SSE CLW) Mr. M. K. Ghosh, SSE/ELS/GMO Mr. Rajesh Singh yadav, JE/RDSO Mr. K. Kasyap, Loco Inspector/GMO

Table-2

During the total run of the load from GMO to Kodarma, the slip was observed at three places, the details of KM location, speed, Tractive effort applied is as follows:

S. No.	Km location	TE applied	Speed in kmph
1.	303	400 kN	31
2.	338	480 kN	20
3.	365	480 kN	20

Table-3

The plot and analysis corresponding to above locations are given below:

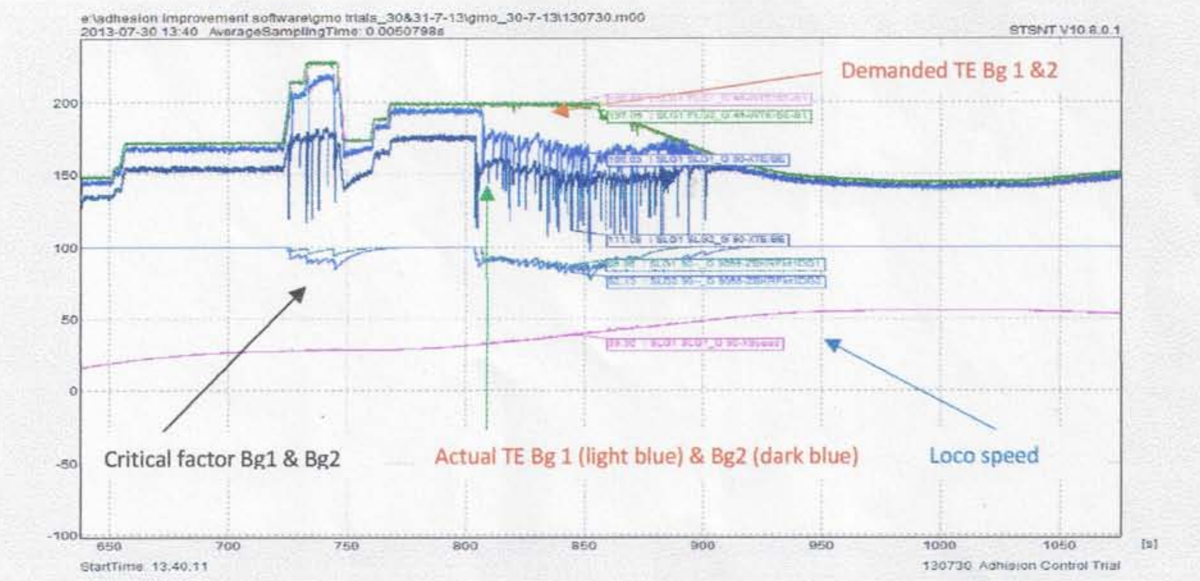

Fig.3

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The analysis of above plot shows that logging started at 13:40 Hrs and slip occurred after 720 sec and prevailed up to 900 seconds. The critical factor ZFKRkt1 is lower in Bogie-2 rather than in Bogie-1 and was up to 0.8. Speed is varying from 27 kmph to 50 kmph during the slip. The demanded TE is 400 kN. The kM location is 303.

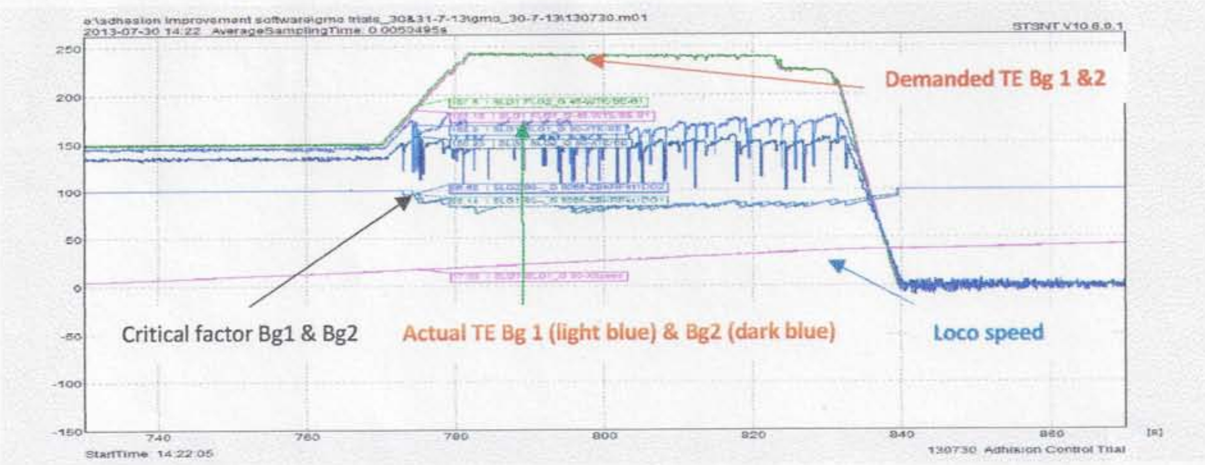

Fig.4

The analysis of above plot shows that logging started at 14:22 Hrs and slip occurred after 775 sec and prevailed up to 830 seconds. The critical factor ZFKRkt1 is almost equal for Bg1 &2 and is up to 0.8. Speed is varying from 17 kmph to 37 kmph during the slip. The demanded TE is 480 kN. The kM location is 338.

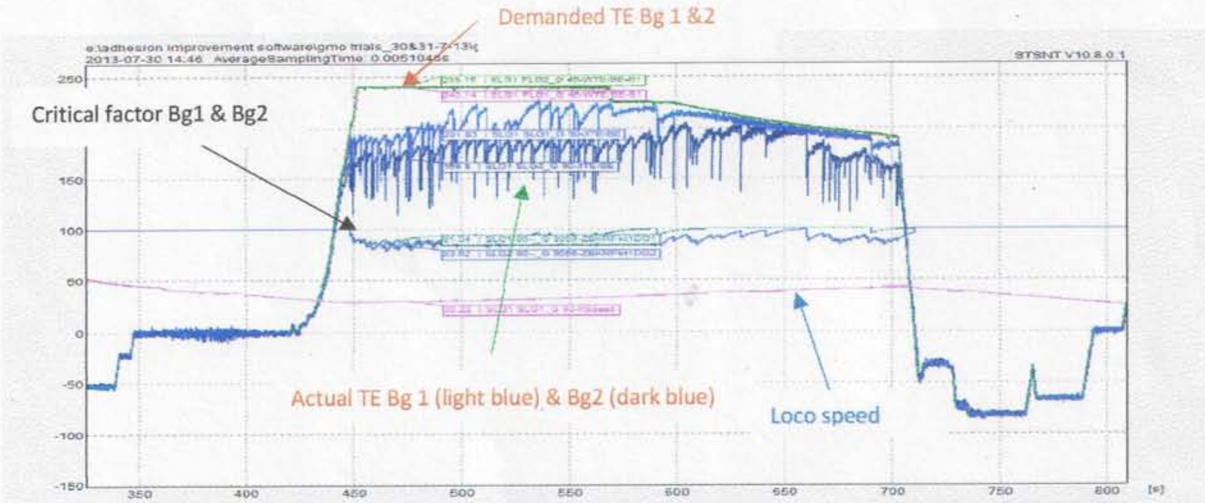

Fig.5

The analysis of above plot shows that logging started at 14:45 and slip occurred after 450 sec and prevailed up to 700 seconds. The critical factor ZFKRkt1 is almost equal for Bg1 &2 and is up to 0.8. Speed is varying from 29 kmph to 42 kmph during the slip. The demanded TE is 480 kN. The kM location is 365.

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It was noted during the trial that auto sanding was not taking place. The probable reason for the same may be that the conditions implemented for auto sanding are not satisfied during the trial as slip was not much. However this issue was again discussed with M/s BTIL and M/s BTIL advised to monitor some more internal signals for investigating the cause.

Further trials were done on 31-7-13 with unmodified (existing) software, the details are as follows:

With existing (unmodified) Software	
Section	Gomoh to Kodarma
Date of trial	31-7-2013
Locomotive under trial	WAG9 – 31044
Departure (GMO)	14:44 Hrs
Arrival (Kodarma)	17:34 Hrs
Driver	Shri Ashok Kumar IV
Assistant Driver	Shri Barun Kumar
Trailing Load	59 BOXN + 1dead Loco (WAP4)
Total Load	5265+112: 5377 Tonnes
Banking	NIL
Weather	Rainy
Accompanied by	Mr. V. K. Singh, Dy. Dir/RDSO Mr. Arun Pan (SSE CLW) Mr. M. K. Ghosh, SSE/ELS/GMO Mr. Rajesh Singh Yadav, JE/RDSO Mr. K. Kasyap, Loco Inspector/GMO

Table-4

The same signals monitored on 30-7-13 were also monitored in this trial. Though it was tried to obtain the same TE and speed on the locations where slip were experienced during previous trial on 30-7-13 however only one location could match with the desired parameters. Analysis of data saved during this case has shown slip in following condition.

Critical factor Bg1 & Bg2

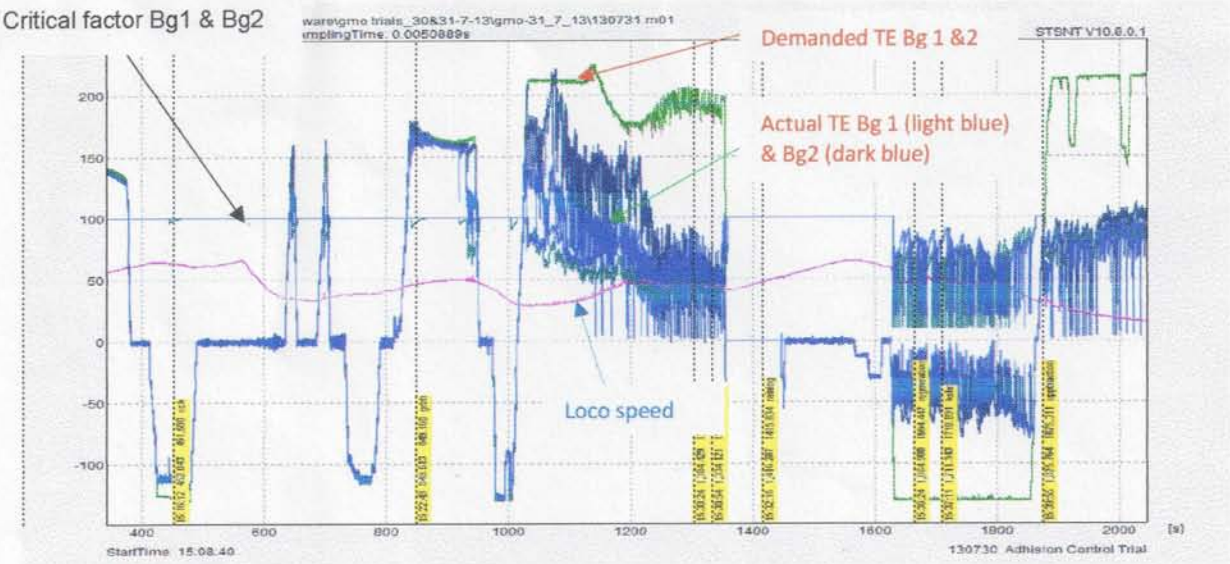

Fig.6

The analysis of above plot shows that logging started at 15.08 Hrs and heavy slip occurred after 1023[rd] sec and prevailed up to 1355[th] seconds. The critical factor ZFKRkt1 for Bogie-1 recorded as 0.34 and for Bogie-2 is equal to 0.32. Speed is varying from 30 kmph to 50 kmph and again dropping to 40 kmph during the slip. In terms of location, the slip occurred near 338 km. At the same location, the plot of trial with modified software is given in Fig.4:

Comparison of both the plots shows that the slip in unmodified (existing) software locomotive is very high and critical factor goes up to 0.34 and 0.32 while in modified software locomotive, the critical factor is 0.8, although speed is lesser. Loco is able to pull the load without much slip.

There is another location where heavy slip has been experienced after 350 kM location where 1:200 gradient starts. This leads to stalling of load and banker was demanded. The plot is as shown below:

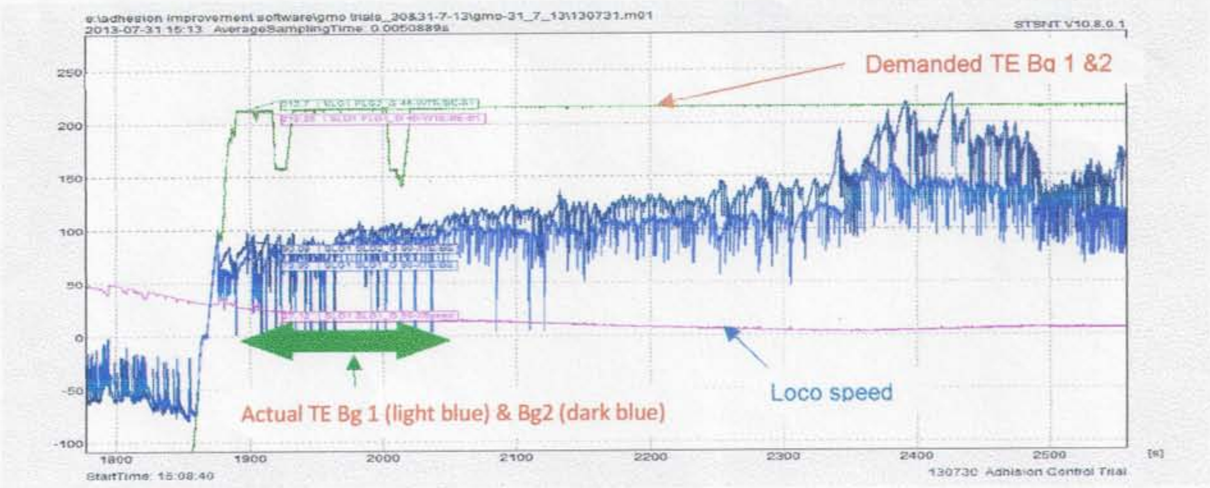

Fig.7

It may be noted that load was more in case of unmodified software 5377 Tonnes w.r.t 5040 Tonnes with modified software and climate conditions in both the cases were not same. Thus, exact comparison for both conditions could not be done since similar physical and loading conditions could not be matched perfectly. In view of this, one more joint trial was done on 21-8-13 by RDSO and ECR. Since it was raining on 21-8-13 in the section hence trial was done with modified software as during the trial with unmodified software on 31-7-13 it was raining in the section. The following are the details of trial:

Trial with modified Software	
Section	Gomoh to Kodarma
Date	21-8-2013
Locomotive	WAG9 – 31265
Departure (GMO)	12:41 Hrs
Arrival (Kodarma)	16:10 Hrs
Driver	Shri Madan Lal
Assistant Driver	Shri N.Thakur
Trailing Load	58 BOXN (BTBP)+ 1Banker Loco (WAG9:31033)
Total Load	5261+123: 5384 Tonnes
Banking	WAG9:31033
Weather	Rainy
Accompanied by	Mr. V. K. Singh, Dy. Dir/RDSO Mr. M. K. Ghosh, SSE/ELS/GMO Mr. S.K Shukla, Loco Inspector/GMO Mr. J.K.Saxena, SSE/RDSO

Table-5

In order to investigate the auto sanding functionality, some additional signals were monitored as per advice of M/s BT.

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S. No	Name of Signal	Description
1.	SLG1 FLG1_G 46-WTE/BE-B1	Demanded Tractive Effort per bogie from FLG
2.	SLG1 FLG2_G 46-WTE/BE-B1	,,
3.	SLG1 SLG1_G 0416*WAZBKRg1	Demanded Tractive Effort per bogie to ASC, included learning effect;
4.	SLG2 SLG2_G 0416*WAZBKRg1	,,
5.	SLG1 90--_G 9060-BSandValv	Signal for auto sanding activation monitoring Bg1
6.	SLG2 90--_G 9060-BSandValv	Signal for auto sanding activation monitoring Bg2
7.	SLG1 90--_G 9011XVist-A1	Speed axle-1_Bogie-1
8.	SLG1 90--_G 9011XVist-A2	Speed axle-1_Bogie-1
9.	SLG1 90--_G 9011XVist-A3	Speed axle-1_Bogie-1
10.	SLG1 SLG1_G 90-Xspeed	Bogie speed
11.	SLG1 90--_G 9017-XVrefFilt	Filtered speed
12.	SLG1 90--_G 9066-ZBKRFkt1DG1	Critical factor when slip occurs Bogie-1
13.	SLG2 90--_G 9066-ZBKRFkt1DG2	Critical factor when slip occurs Bogie-1
14.	SLG1 90--_G 9035-ZBKRdvdtDG1	dv/dt factor during slip
15.	SLG2 90--_G 9035-ZBKRdvdtDG2	dv/dt factor during slip
16.	SLG2 90--_G 9017-XVrefFilt	Filtered speed Bogie-2
17.	SLG2 90--_G 9011XVist-A1	Speed axle-1_Bogie-2
18.	SLG2 90--_G 9011XVist-A2	Speed axle-1_Bogie-2
19.	SLG2 90--_G 9011XVist-A3	Speed axle-1_Bogie-2
20.	SLG2 08--_G 0875-WARedBglsp	LSP indication

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S. No	Name of Signal	Description
21.	SLG1 SLG1_G 90-XTE/BE	Actual TE/BE Bogie-1
22.	SLG1 SLG2_G 90-XTE/BE	Actual TE/BE Bogie-2
23.	SLG1 91--_G 9052-WAZBKR-DG1	Internal signals
24.	SLG2 91--_G 9106-WAZBKR-DG2	Internal signals
25.	SLG1 ASC1_G ASC1*XAZBKRg1	Generated Tractive Effort per bogie1 by ASC1, included learning effect;
26.	SLG2 ASC1_G ASC1*XAZBKRg1	Generated Tractive Effort per bogie2 by ASC, included learning effect;
27.	SLG1 90- _C 9060-BFrgSand	Internal signal to check auto sanding
28.	SLG1 90--_C 9060-BAutoSand	Internal signal to check auto sanding
29.	SLG1 90--_G 9060-BSandFrSLG	Internal signal to check auto sanding
30.	SLG2 90--_C 9060-BFrgSand	Internal signal to check auto sanding
31.	SLG2 90--_C 9060-BAutoSand	Internal signal to check auto sanding
32.	SLG2 90--_G 9060-BSandFrSLG	Internal signal to check auto sanding
33.	SLG1 91--_G 9106-WAZBK-DG1	Internal signals
34.	SLG2 91--_G 9106-WAZBK-DG2	Internal signals
35.	SLG1 90--_G9011-XVist-DG1	Internal signals
36.	SLG2 90--_G9011-XVist-DG2	Internal signals
37.	SLG1 90-_C9060-XdvdtVref	Internal signals
38.	SLG2 90-_C9060-XdvdtVref	Internal signals

Table-6

During the trial on 31-7-13, the load was stalled after 350 km location at up gradient of 1:200 while reducing the speed up to 27 kmph. Hence, during this trial also it was decided to negotiate the up gradient of 1:200 after 350 kM by 26-27 kmph speed with same TE demand. The plots from both the trials are as follows:

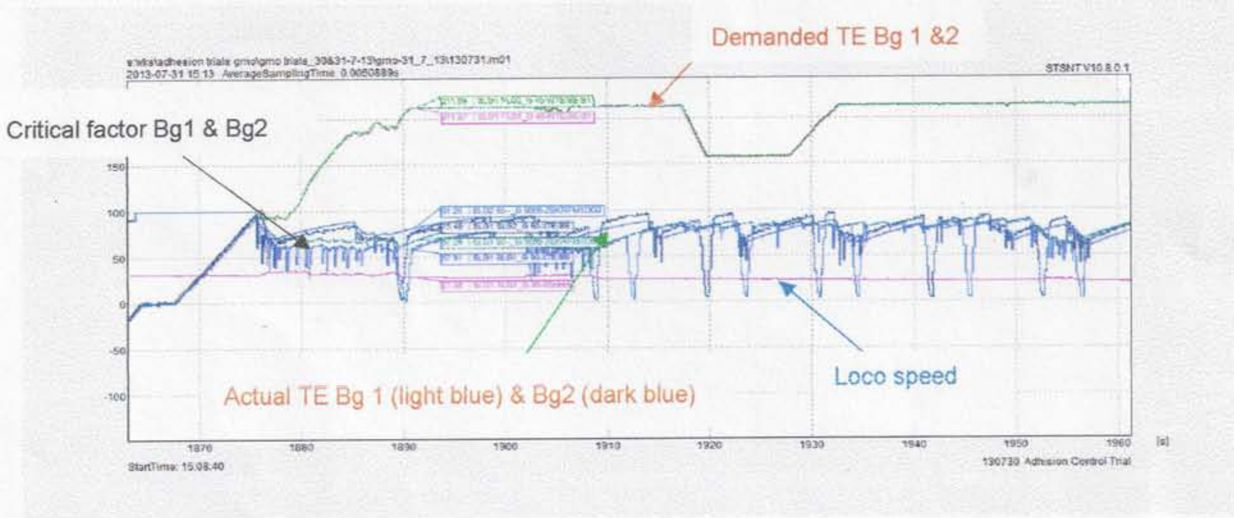

Fig.8

Plot with existing software, Starting of Test: Time : 15:40:18 Location: Between 350 & 351 kM, Gradient: Up gradient of 1:200 starts., Speed : 27 kmph

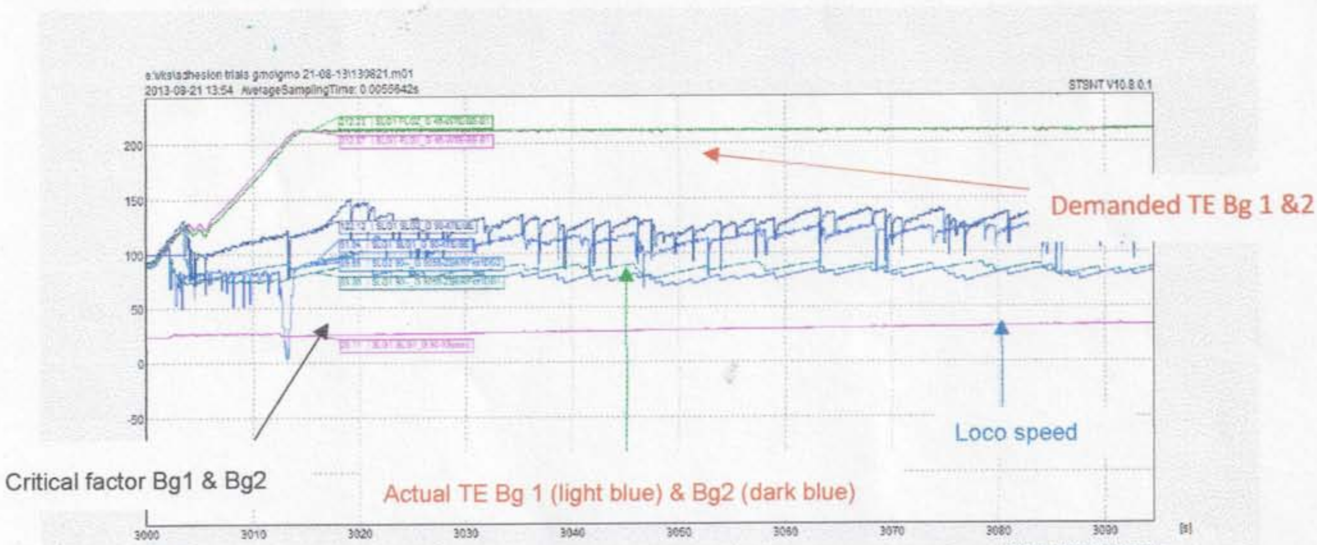

Fig.9

Plot with modified software, Starting of Test: Time : 14:43; Location: Between 350 & 351 kM, Gradient: Up gradient of 1:200 starts., Speed : 25.7kmph

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The above plots show the starting of the test. During starting, slip started and actual TE becomes zero many times with existing software where as with modified software the actual TE is steady and is not reducing to zero at any time. Due to actual TE generated becoming zero many times in existing software initially, the speed of loco is reducing. The affect is more clearly visible in following plots which are for long duration:

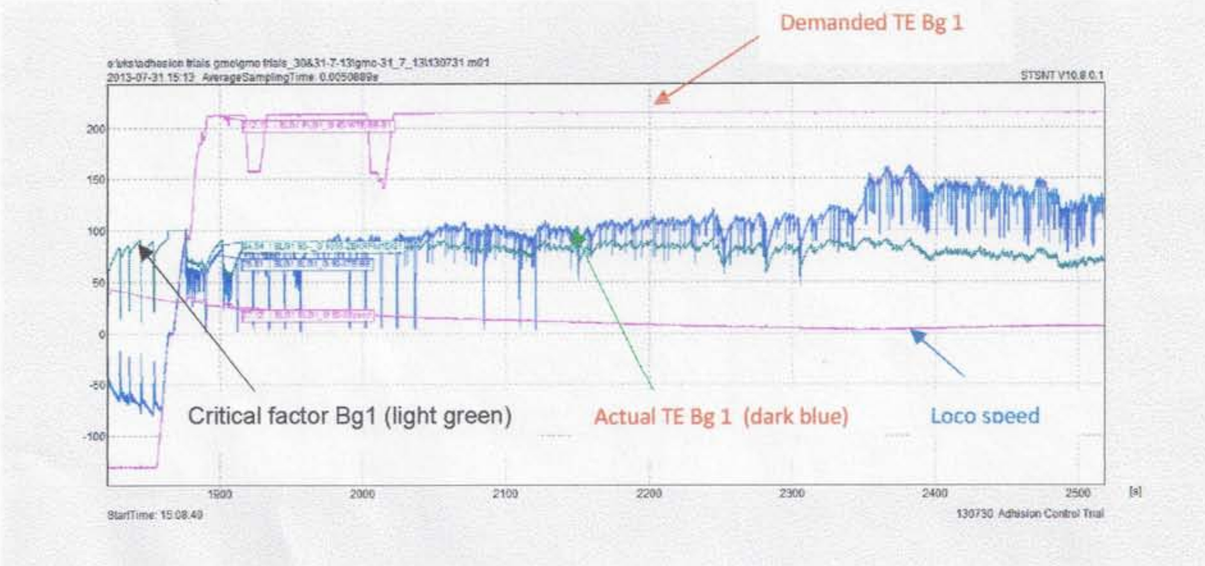

Fig.10

Behavior Bogie-1 during 600 seconds (existing)

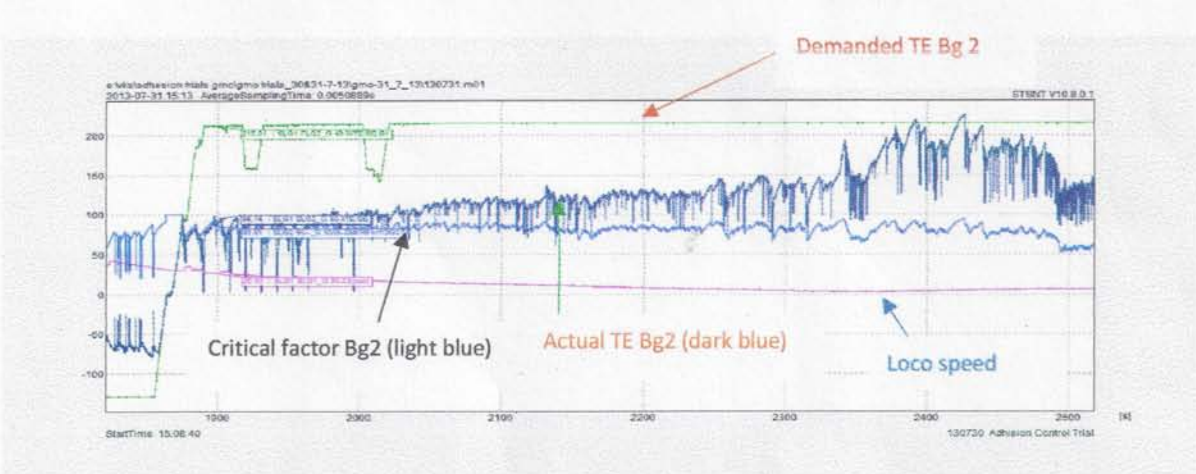

Fig.11

Behavior Bogie-2 during 600 seconds (existing)

The above plots show unstable behavior. There is continuous slip with large peaks of reduction in actual TE. The actual TE is reducing some times to nearly zero in most wanting situations. Average actual TE less than 100 kN initially, then 100 kN during mid period and touching sometimes 150 kN afterwards were observed however speed becomes very less up to 5 kmph. The behavior of loco with modified software during similar condition is as follows:

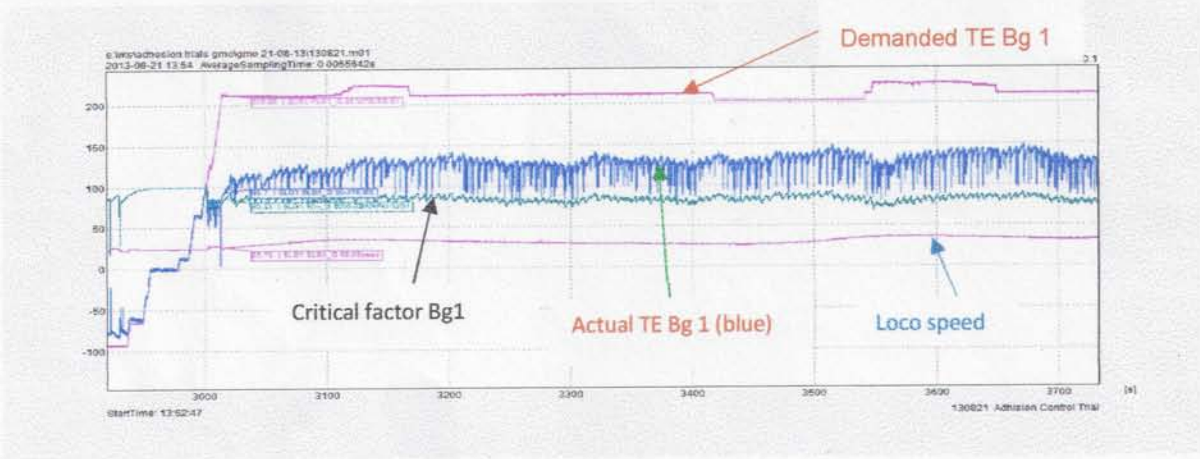

Fig.12

Behavior Bogie-1 TE during 600 seconds (modified software)

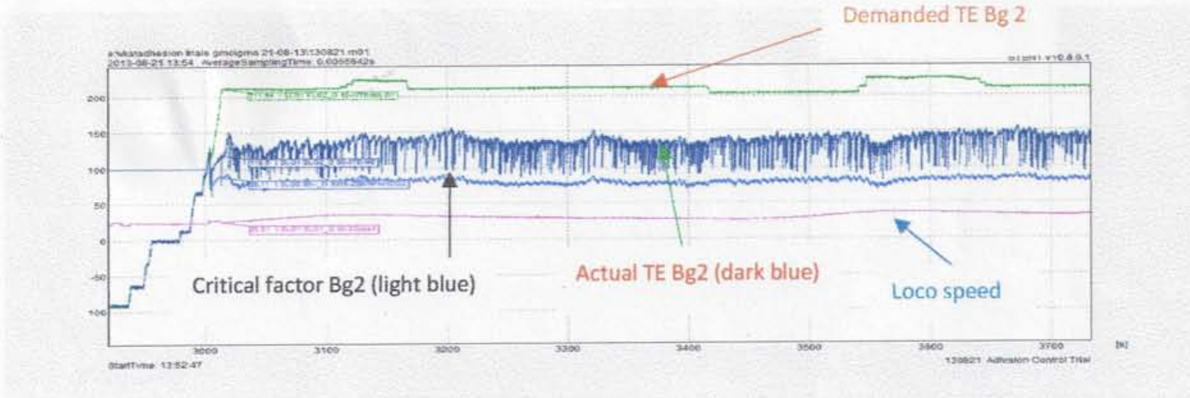

Fig.13

Behavior Bogie-2 TE during 600 seconds (modified software)

The above plots with modified software show stable behavior. There is continuous slip in this case also however large peaks of reduction in actual TE are not there. Average actual TE observed is more than 140 kN for most of the time, not below 100kN and touching 150kN some times. Speed never falls below 25 kmph.

The combined effect of bogie-1& Bogie-2 in existing software is as shown in Fig 14:

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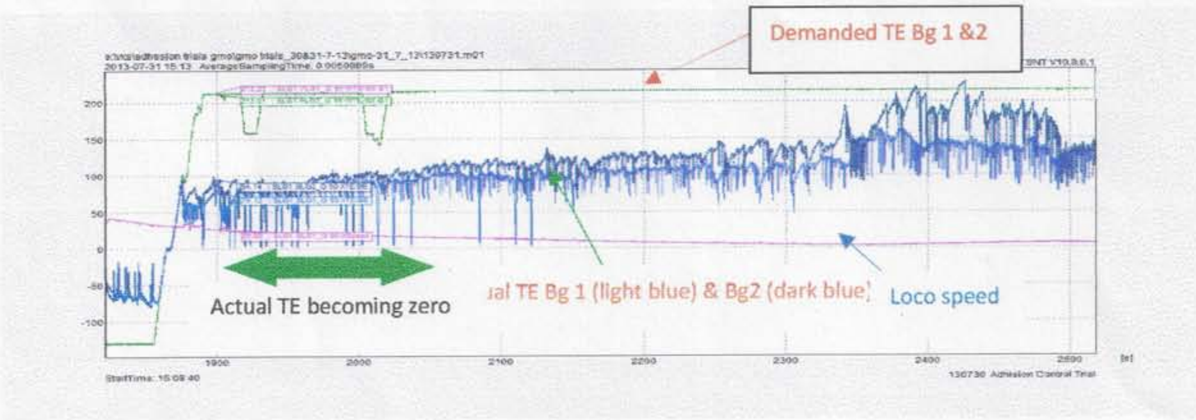

Fig.14

Behavior of both Bogie's TE during 600 seconds (existing)

The above plots with unmodified software show unstable behavior, Actual TE between 0 to 200 kN for both bogies against demand of 422 kN from 1900 to 2230 seconds and then from 100 to 250kN up to 2330 seconds and Load stalled and banker demanded.

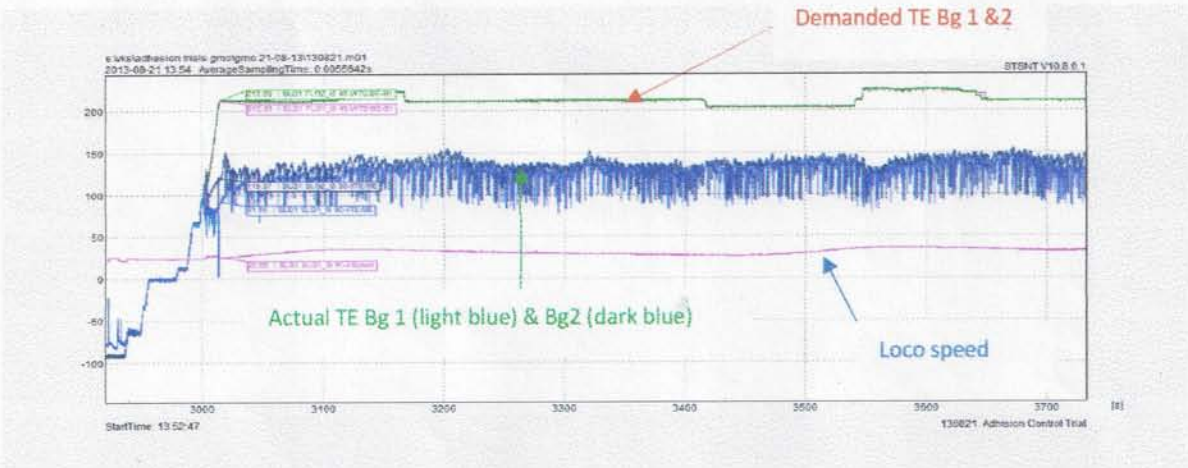

Fig.15

Behavior both Bogies during 600 seconds (modified)

The above plots with modified software show stable behavior, actual TE between 250 to 300kN all the time and hence there is no reduction of speed below 25 kmph.

The speed plot for both cases i.e. for short duration (60-80 seconds) and long duration (600 seconds) show the above phenomenon more clearly.

Fig.16

Speed-Time plot (existing software-short duration: 60 seconds)

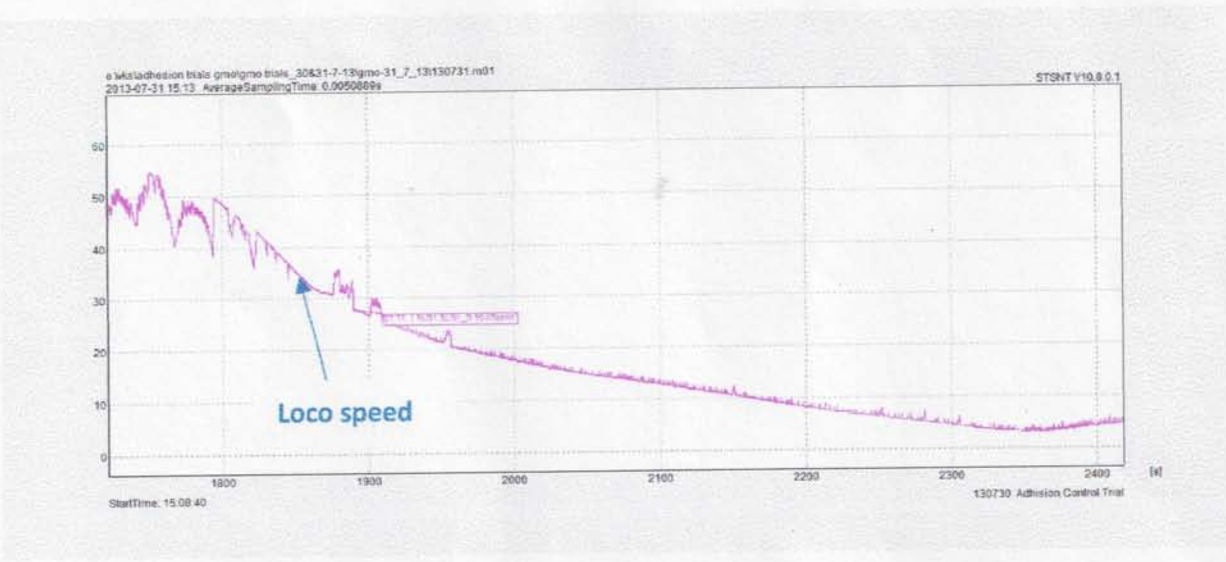

Fig.17

Speed-Time plot (existing software-longer duration: 600 seconds)

Speed is continuously reducing as the generated TE is not sufficient to pull the train.

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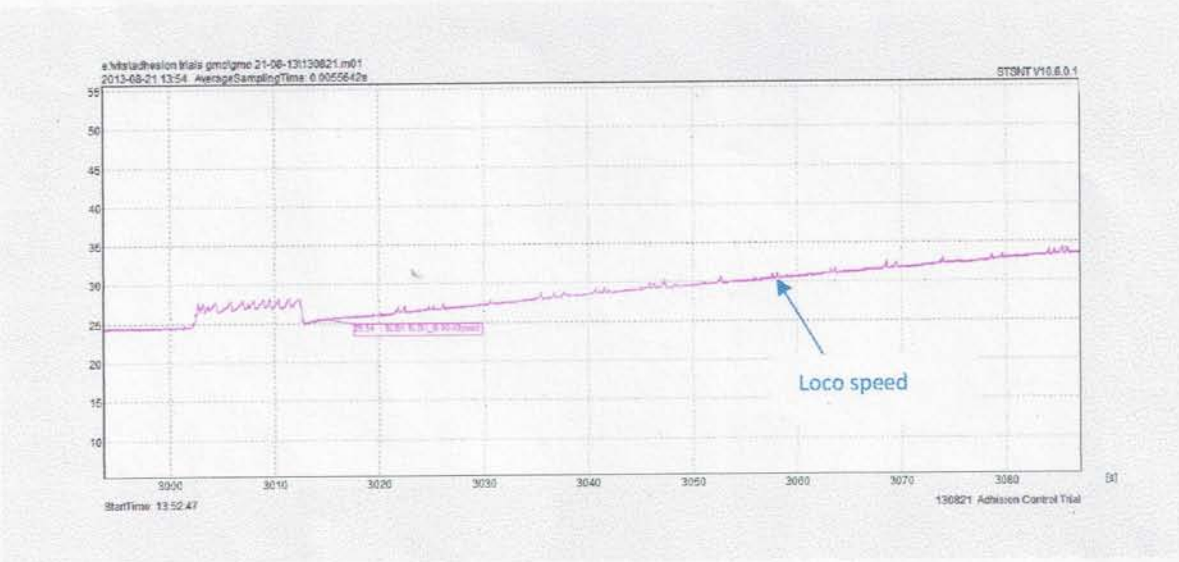

Fig.18

Speed-Time plot (modified software-short duration: 80 seconds)

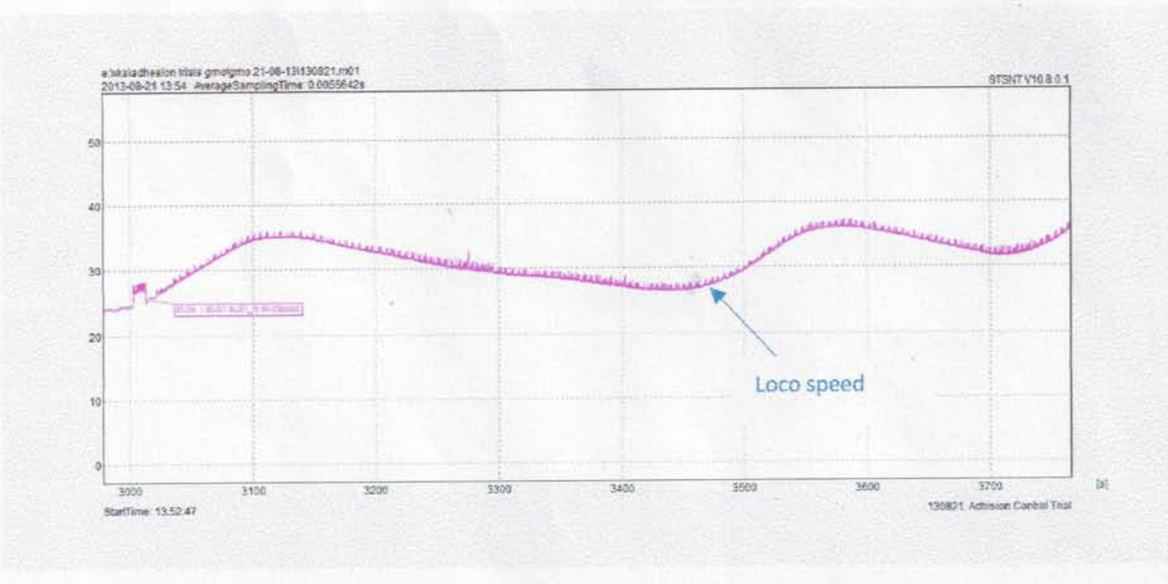

Fig.20

Speed-Time plot (modified software-long duration: 700 seconds)

The speed is increasing initially after that when complete load is on up gradient, speed is reducing up to 27 kmph and is again increasing.

It may be noted that in existing software manual sanding was done by driver when speed started reducing while in modified software auto sanding was in function.

Prepared by	Checked by
DDSE/TPL	DSE/TPL

5.0 CONCLUSION:

The extensive trials done in DHN division of ECR with modified and existing adhesion control software of WAG9 locomotive have clearly established that the tractive effort generated by ASC improves in case of modified software w.r.t existing software, during wheel slipping conditions. This is due to following improvements in modified software:

- Slow rate of reduction of generated TE
- Optimised auto sanding