TRACK'S SLIP EITHER RELATIVE DIFFERENCE OF DISPLACEMENTS (RDD) DURING DOZER'S TURNING

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Abstract: The field investigations of SG-15HS dozer turning were described in this paper. Mutual dependency between slip and relative difference of displacements (RDD*)* was tested both for separate signals from left and right track and for theirs mean value. The procedure of using two side measuring wheels was shown and then discussed. Its advantages and disadvantages were pointed out as well as range of proper applying of this. The possibility of using GPS for calculation of track's displacements was analysed.

Keywords: Dozer, track's slip, turning, relative difference of displacements, GPS.

1 INTRODUCTION

Every mathematical model of track machine's movement contains a lot of factors describing this phenomenon. One of them is longitudinal slip of tracks vs. ground.

We know that value of slip is submitted to dynamic changes but for simulation simplicity almost every creator of model neglects that fact and applies fundamental assumption about fixed slip value during particular driving both for rigid and for flexible track's belts.

How important is this rejection of slip's dependence on time? What is admissible range of using this factor as constant in traction force prediction procedure? What new coefficient could replace slip function in thrust equation not only for straight moving but also for turning?

In the papers [1,2] it was suggested that using of relative difference of displacements (RDD) could be useful tool for analysis of track machine's dynamic (accelerated or braked) movement. Instead of rapidly changing slip of tracks i - counted in classic way as relative difference of theoretical speed v_T and real one v_R- see (1) - one can insert the RDD value into terra-mechanic equation e.g. for thrust force value.

RDD should be establish in accordance with (2) as a relative difference of theoretical displacement of machine S_T and real shifting S_R.

$$i(t_a) = \frac{v_T(t_a) - v_R(t_a)}{v_T(t_a)} \tag{1}$$

$$RDD(t_a) = \frac{S_T(t_a) - S_R(t_a)}{S_T(t_a)} = 1 - \frac{S_R(t_a)}{S_T(t_a)} \tag{2}$$

Theoretical displacement S_T was a result of multiplication of recorded sprocket's angle of rotation α and track link pin's radius r_p. Velocity ω is counted as $d\alpha/dt$. Then for straight moving

$$S_T(t_a) = \int_0^{t_a} v_T(t)dt = r_p \int_0^{t_a} \omega(t)dt \tag{3}$$

$$S_R(t_a) = \int_0^{t_a} v_R(t)dt = r_p \int_0^{t_a} \omega(t)[1 - i(t)]dt \tag{4}$$

Now we can write mutual relationships between slip i and RDD, e.g.

$$RDD(t_a) = \frac{1}{\alpha(t_a)} \int_0^{t_a} i(t) * \omega(t)dt \tag{5}$$

$$i(t_a) = \frac{1}{\omega(t_a)} \frac{d}{dt}[RDD(t_a) * \alpha(t_a)] = $$
$$= \frac{d}{d\alpha}[RDD(t_a) * \alpha(t_a)] \tag{6}$$

For straight and uniform motion we obtain that in every moment slip is identical with RDD (!).

During turning we observe dynamic phenomena connected with variable value of turning radius both for inner and outer tracks.

A certain shiftings of temporary turning centres occur so precise calculations of real values of slip are hardly possible even with two Doppel speedometers (one for each track).

Therefore we should establish simplified method for describing of turning process of tracked machine with the help of RDD (computed separately for both tracks).

The equation (5) is naturally valid for each track (RDD_{ltr}, RDD_{rtr}). For any moment in time author suggests applying of RDD's arithmetic mean.

It is given below (ltr≡left track, rtr≡right track):

$$RDD_{MEAN} = \frac{RDD_{ltr} + RDD_{rtr}}{2} =$$

$$= 1 - \frac{\int \omega_{ltr}(t)[1 - i_{ltr}(t)]dt * \int \omega_{rtr}(t)dt}{2 * \int \omega_{ltr}(t)dt * \int \omega_{rtr}(t)dt} +$$

$$+ \frac{\int \omega_{rtr}(t)[1 - i_{rtr}(t)]dt * \int \omega_{ltr}(t)dt}{2 * \int \omega_{ltr}(t)dt * \int \omega_{rtr}(t)dt} \qquad (7)$$

The next step was field investigation for confirmation assumption about possibility of replacing mean value of turning tracks' slip by mean value of theirs RDD.

2 FIELD TESTS AND RESULTS

The investigated dozer was hydrostatic HSW SG-15HS (17.8 Mg; 130 kW), moving independently (when unloaded) or towing HSW 560 wheel loader (weight around 38 Mg).

This loader was applied as towed vehicle with varying value of its rolling resistance (different shifts, even reverse gear) to simulate pulsating and not uniform loading force.

The experiments were made in different four configurations: two for unloaded dozer (a, b) and two for dozer loaded by towed wheel loader (c, d).

Fig.1 Unloaded dozer on flat, rigid surface made of cast-iron panels (a) during circular turning to the left (turning radius is 19 m)

Fig.2 Unloaded dozer on deformable surface of clayey sand (b) during straight moving

Experiments were carrying out during straight moving then turning with different turning radius.

Fig.3 Loaded dozer on flat, rigid surface made of cast-iron panels (c) during circular turning to the right (turning radius 12 m)

Fig.4 Loaded dozer on deformable surface of clayey sand (d) during turning with unknown turning radius

Four signals were at the same time registered: r.p.s. of hydraulic motors of both sprockets and r.p.s. of left and right measuring wheels (fig.5, 6).

Fig.5 Dozer with both measuring wheels

Fig.6 Left measuring wheel

From r.p.s. of left track sprocket's hydraulic motor we obtained theoretical speed of left track. The same procedure was applied for right track.

From r.p.s. of left measuring wheel we calculated linear velocity and then real displacement of that wheel and consequently of left track.

We had to taking into account reduction of wheel displacement to longitudinal plane of track symmetry to obtain proper real displacement of left track.

The same procedure was applied for right measuring wheel to establish real displacement_of right track.

For precise measuring of vehicle displacement versus ground we could use Doppler speedometer.

However, during turning of track on soft surface the outside part of ground is destroyed by side part of track links and surface intensively bulges up so the problem of proper attachment of Doppler device becomes because of rapid changes of distance from it to soil.

Another trouble was connected with place of fixing this instrument along track frames on either sides of dozer. Attachments in front of idlers or behind the sprockets were not involved because of technical complications or damaged ground.

But the most important problem was necessity of simultaneous applying two Doppler's units for investigation of turning processes. That was at the moment beyond author power.

To avoid all these problems, during initial step of investigation we used two additional measuring wheels (e.g. prepared bicycle wheels – fig.5, 6). Wheels could rotate in relation to arched bearer attached to track frames in a middle of them.

Offset of wheel contact point from track frame plane of symmetry was 0.65 m.

Both wheels could move vertically and were adjusted to be vertical and parallel to track before and after each test moving.

Author was naturally conscious of certain imperfection of such a measuring technique generally proper for straight moving (for example applying of well-known "fifth wheel") but total error seemed to be not large. First of all it was created by lateral bracing of wheels.

Moreover, another source of error could be neglecting of differences between measuring wheel's displacement and the real displacement of appropriate track caused by shifting of temporary turning centre from central point of contact area during driving with slip.

To calculate theoretical displacements of tracks (S_{Tltr}, S_{Trtr}), we had to integrate recorded previously functions of theoretical speed (v_{Tltr}, v_{Trtr}) in accordance with relationship (3).

Instead, to count real displacements of tracks (S_{Rltr}, S_{Rrtr}) we needed to correct equations of measuring wheel displacements to refer it to longitudinal plane of track symmetry by multiplication displacements of wheels (S_{Rlwh}, S_{Rrwh}) by individual factors (ξ_{lwh}, ξ_{rwh}).

These corrections of acquired from measuring wheels recorded data were obligatory only while turning.

It should be mentioned that in a case of any mathematical problems with wheel displacement or sprocket speed functions we could use technique based on applying of *trendline* of established equation instead of this relationship. Such a procedure was tested in [1, 2] when discontinuity or another troubles were occur.

When dozer first drove straight and then after certain time operator adjusted it to turn, the initial moment of applying correction factors (ξ_{lwh}, ξ_{rwh}) was the point when two sprocket's speeds began to be significantly differed.

During experiments on rigid surface we knew value of turning radius (12 m, 15 m, 19 m) so correction factors were based on assumption of the same value of angular velocity of outer and inner wheels (i.e. after appropriate correction central points of both tracks) versus turning centre.

When turning on deformable ground precise value of turning radius was practically unknown, therefore displacements of both wheels were corrected taking into account only geometric spacing of measuring wheels' contact points and virtually established middle points of tracks.

Selected results were shown of figures 7÷10 (in accordance with equations (1) and (7) respectively).

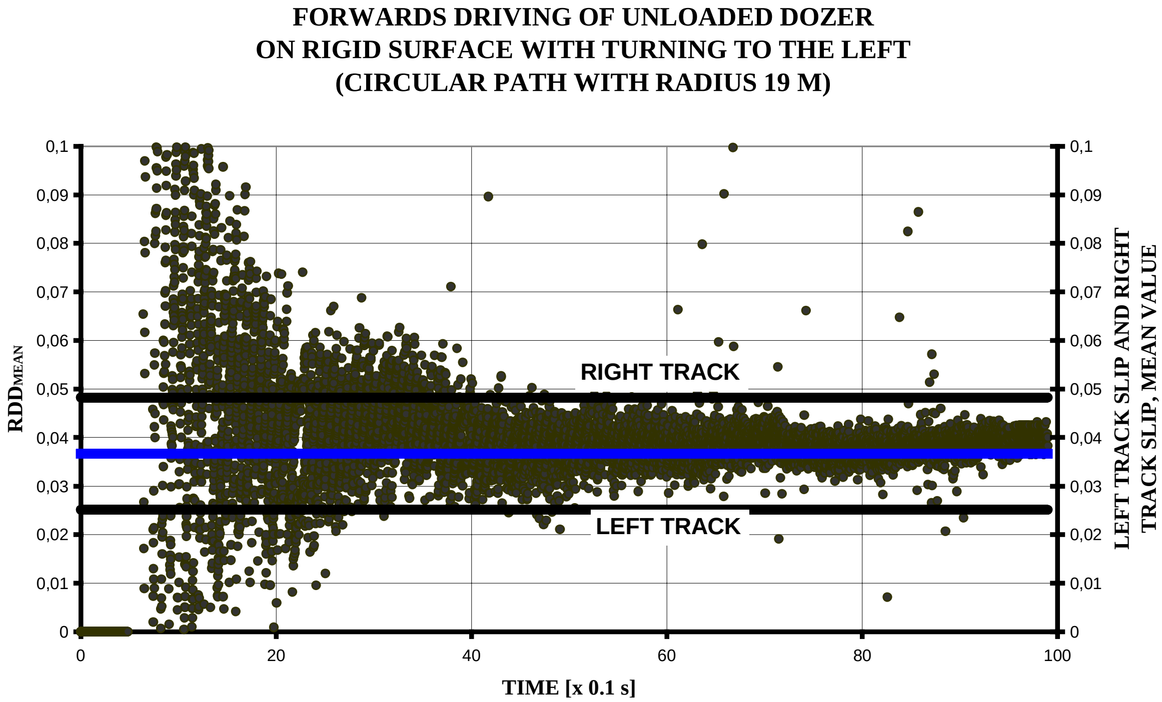

Fig.7 RDD_{MEAN} and slips of both tracks during forwards driving with turning on rigid surface

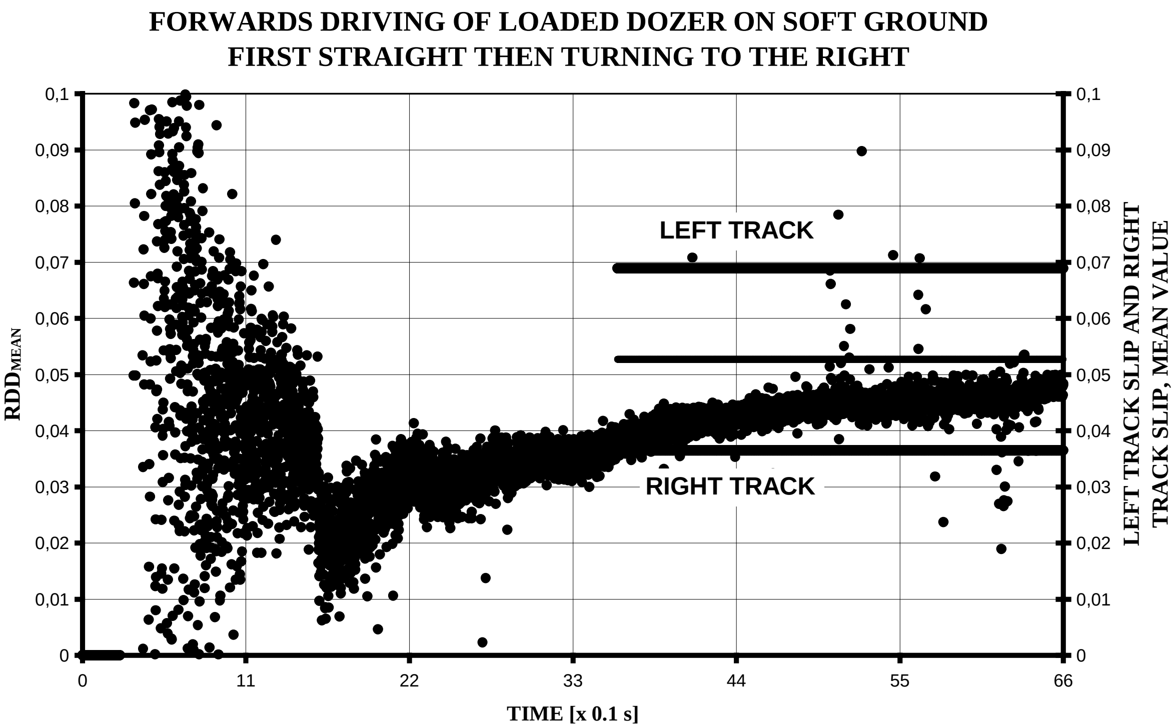

Fig.8 RDD_{MEAN} and slips of both tracks during forwards straight driving and then turning on soft ground

BACKWARDS DRIVING OF UNLOADED DOZER ON RIGID SURFACE WITH TURNING TO THE RIGHT (CIRCULAR PATH WITH RADIUS 19 M)

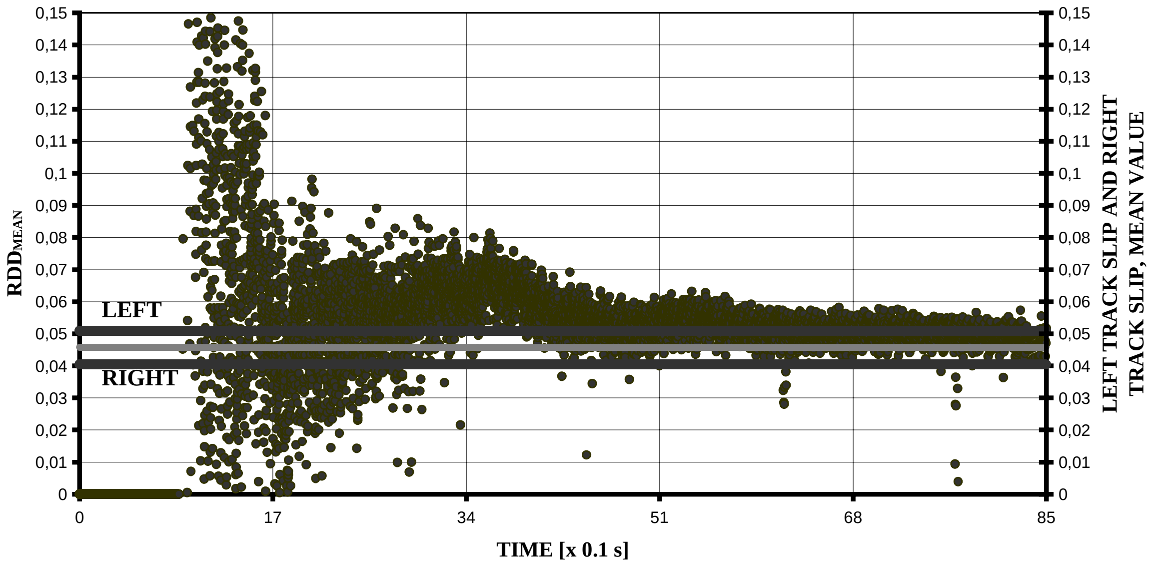

Fig.9 RDD_{MEAN} and slips of both tracks during backwards driving with turning on rigid surface

FORWARDS DRIVING OF LOADED DOZER ON SOFT GROUND WITH VERY MILD TURNING TO THE LEFT TILL LOSS OF MOBILITY

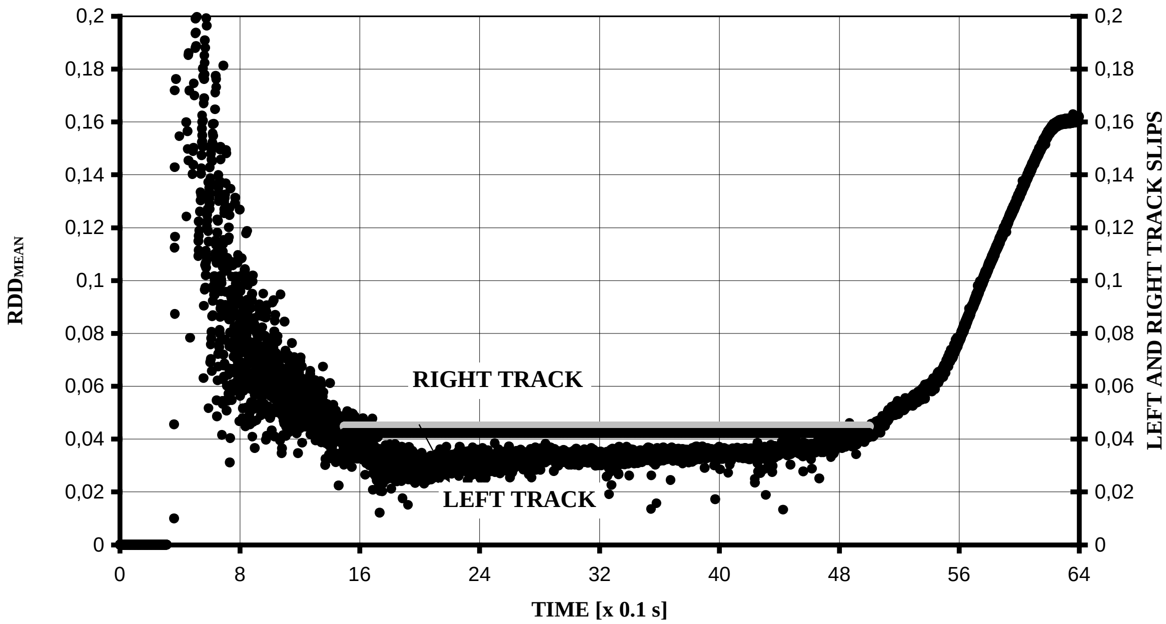

Fig. 10 RDD_{MEAN} and slips of both tracks during forwards driving with very mild turning to the left till loss of mobility

3 CONCLUSIONS

The classic definition of slip has limited applying area. It can be use safely for steady, horizontal and straight movement of unloaded (single) dozer basically without gear shifting. In another kinds of driving the influence of time is too strong to neglect it [1, 2].

Above mentioned restrictions are particularly evident in a moment of reduction and finally loss of dozer's mobility (fig. 10).

During accelerated driving of loaded dozer (in a moment of gear shifting as well) slip definition is useless because of its uncontinuity or huge data scattering.

The good tool for tractive analyse appeared regression *trendline* to replace scattered data points received during straight driving as well as during turning of vehicle.

Results of field investigations shown that mean value of RDD could replace mean slip of track both for straight driving ([1, 2]) and for slow turning of dozer. The observed scattering of data was relatively small and maximum error did not exceed several percent.

Such a phenomenon was observed both during forwards and backwards driving of dozer (fig. 9).

Applied slip curves were straight lines because of fact that using of non-linear curves as slip functions' illustrations had no sense in steady turning without real acceleration.

RDD_{MEAN} function quite well described quasi-static process of dozer's turning i.e. driving with constant magnitude of velocity vector but with varying direction.

The measuring methodology based on applying of side wheels appeared to be essentially good however for initial part of investigation only. For more precise measurement obtained accuracy is unsuffitient.

Values of calculated track slips were pretty small ($0.025 \div 0.070$) therefore shifting of turning centres from middle points of tracks were not large as well.

Therefore we could assume that point in when dozer longitudinal plane of symmetry and line connected these temporary turning centres intersect each other would be representative for measuring in that point real velocity of vehicle versus ground by using of single unit of Doppler speedometer only.

Another method of measuring single point displacement is using GPS. By means of this network we could easily establish real position of machine and its displacement.

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