Printing：17/10/30

Torsion Type Gate

Running of a Roller Off its Rail

TeraMatsu

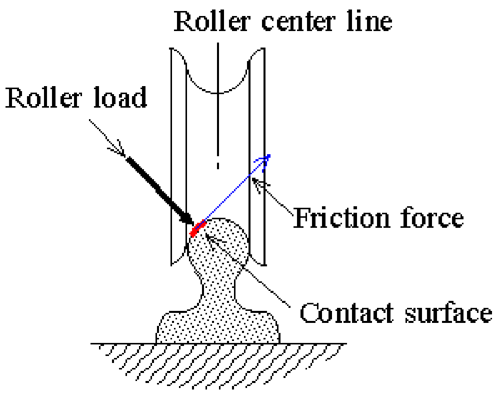
Contents

Page

１. Introduction

This material intends to explain a back ground of the formulas which are given in the patent application as a procedure to evaluate possibility of a roller's running off its rail.

Although there exists really no phenomenon of the running off, this study was made based upon a hypothesis that there must be contingent causes which may result in such phenomenon. In addition to the formulas explanation, the material tries to sharpen nature of the uncomprehended phenomenon through an objective analysis on the two examples of a roller's running off its rail.



Conclusion is as follows（Refer to the above picture）.

（１）Although there is actually no roller's running off phenomenon, it was supposed that the phenomenon exists because of the uncertainty in rail friction and roller load.

（２）With a start of roller running,

①The roller moves toward the roller center line due to the friction force of the contact surface and eventually the contact surface moves in reverse direction to the roller movement.

②As soon as the contact surface arrives at a roller width's end, roller's running off its rail starts and the roller gets run off at an accelerated pace.

③The roller's running off its rail will not occur if the contact surface movement ceases due to equivalence between a movement power and a blocking power of roller movements.

（３）The evaluation formulas given in the patent application are highly reliable.

Contents of the material are as follows

①Does phenomenon of a roller's running off its rail really exist ?

②Evaluation formulas of the patent application

③Study on examples of roller's running off its rail phenomena

Example １：Roller movement power at a start of roller running

Example ２：Stable point of the contact surface

④Image of roller's running off its rail phenomena

2. Does phenomenon of a roller's running off its rail really exist ?

Suppose a roller runs off its rail while the roller is running on the rail with loads of the vertical deadweight of gate body and horizontal water pressure, then the running off force could be the one existing on the roller's contact surface with the rail and it should be a friction force created by a downward component of movement of a point on the roller's rotation plane.

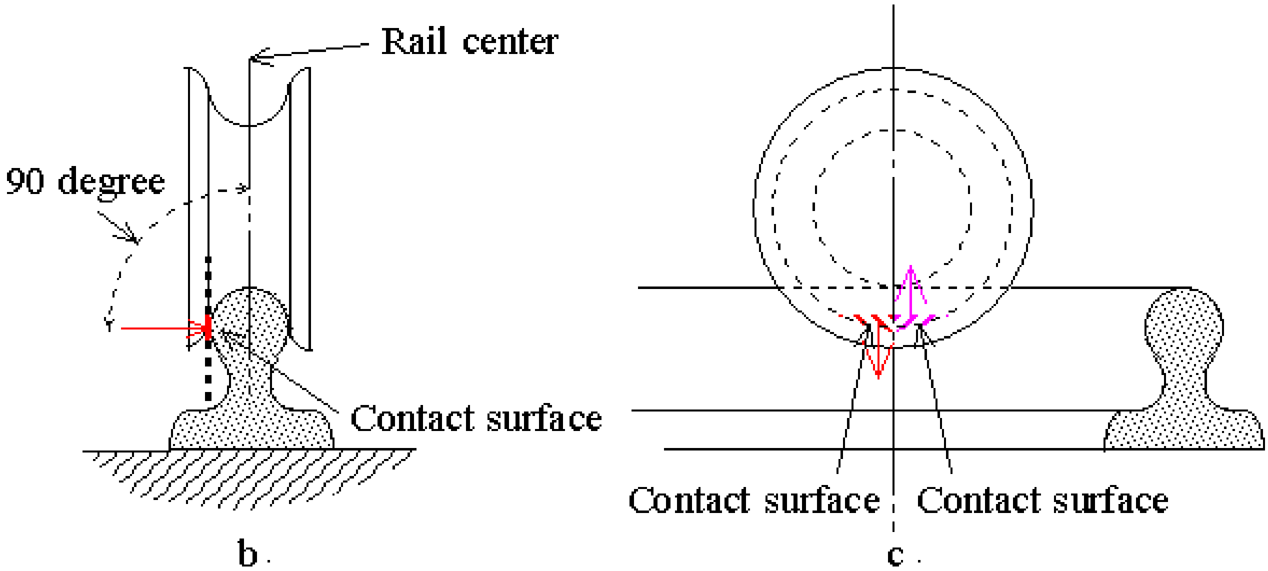


Fig. 1.-1 A roller contact surface with its rail

Fig. 1-1 shows a roller contact surface with its rail. The sketch b in the figure shows, for instance, a roller whose contact surface stays at a location 90 degree to the roller center line. The sketch c in the figure is a side view of the sketch b and the red and pink arrows show the friction force on the contact surface. The friction forces on the both side of roller center line work in opposite direction each other. That is because a vertical component of movement of a point on the rotation plane due to the rotation of the roller is in opposite direction at each side of the roller center line. The friction forces on the both side cancel each other out and do not work as a running off force. The cancelling out occurs at all contact positions other than 90 degree to the roller center line and no running off phenomenon happens as a consequence. But human intuitions are important and it was concluded that the running off phenomenon exists because it is actually possible that a state of this stability may be disrupted by incidental elements. The incidental element likely relates to uncertainties of the load direction, the friction coefficient, the contact surface property (for instance shape and strain and stress distributions) etc. and a result, for instance, may be the state in which the left hand side contact surface vanishes. At a state of stability, anti-rotation moment will works on the roller due to friction forces of the left and right side contact surfaces. It is a part of rolling friction and counted in an operating load of the gate as well as friction forces added by horizontal components of movement of a point on the rotation plane due to the roller rotation.

3． Evaluation formulas of the patent application

3．1　Description of the patent application

Force to make a roller run off its rail is a friction force on the contact surface created by a downward component of movement of a point on the rotation plane due to the rotation of the roller. This friction force is given by Formula (3.-1). On the other hand, an off-running prevention force or a force to prevent the roller from running off the rail is a component parallel to the roller center line of the roller load and given by Formula (3.-2).

Friction force = roller load x cos (90 - θ) x friction coefficient of contact surface ・・・・・(3.-1)
Off-running prevention force = roller load x sin (90 - θ) ・・・・・(3.-2)

3．2　A back ground of the formulas

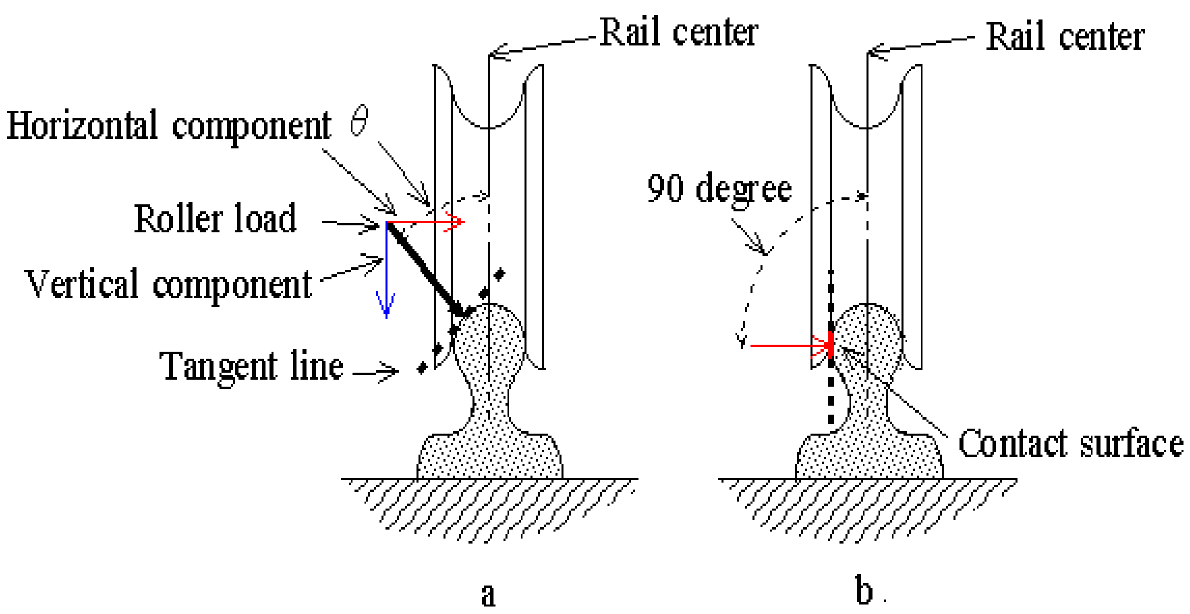


Fig. 3.-1　Back ground of the formulas（3.-１）and（3.-2）

The back ground of Formula (3.-1) and (3.-2) are explained according to Fig. 3.-1. The sketch ａ in the figure shows the roller in a resting state and the roller tread contacts the rail head due to the roller load including gate's own weight, water pressure load etc. With the start of roller running, the rail contact surface changes its position along the tangent line and roller's running off the rail will start after the contact surface arrives at the position shown on the sketch ｂ. Accordingly a friction force in the state of ｂ is a force to make a roller run off its rail and a downward component of the roller load is a force to prevent the roller from running off the rail, and their formulas are given as follows.

Roller's running off its rail force = friction force =
a horizontal component of the roller load x friction coefficient of contact surface =
roller load x sin (?) x friction coefficient of contact surface ・・・(3.-1')

Off-running prevention force = a vertical component of the roller load = roller load x cos (?) ・・(3.-2')

The both formulas show a back ground of the formula (3-1) and (3-2) which are the evaluation formulas of the patent application. Accordingly it is a prior condition of the evaluation formulas on the patent application that the cross-sectional form of a tread surface of the roller is the 180 degrees concave circular arc.

A safety factor against roller's running off its rail is accordingly defined as follows.

Safety factor = off-running prevention force ÷ friction force =
１÷tan (θ) ÷friction coefficient of contact surface ・・・・・(3.-3)

３．３ Calculation of the safety factor

Table 3.-1 Preliminary calculation resuit of the safty factor

Frictional C.	Cf=0.1	Cf=0.2	Cf=0.3	Cf=0.4	Cf=0.5	Cf=0.6	Cf=0.7
θ（度）	Safty factor						
10.00			18.90	14.18	11.34	9.45	8.10
12.00			15.68	11.76	9.41	7.84	6.72
14.04		20.00	13.33	10.00	8.00	6.67	5.71
18.00		15.39	10.26	7.69	6.16	5.13	4.40
22.00		12.38	8.25	6.19	4.95	4.13	3.54
26.56	20.00	10.00	6.67	5.00	4.00	3.33	2.86
28.00	18.81	9.40	6.27	4.70	3.76	3.13	2.69
30.00	17.32	8.66	5.77	4.33	3.46	2.89	2.47
35.00	14.28	7.14	4.76	3.57	2.86	2.38	2.04
40.00	11.92	5.96	3.97	2.98	2.38	1.99	1.70
45.00	10.00	5.00	3.33	2.50	2.00	1.67	1.43
50.00	8.39	4.20	2.80	2.10	1.68	1.40	1.20
55.01	7.00	3.50	2.33	1.75	1.40	1.17	1.00
59.04	6.00	3.00	2.00	1.50	1.20	1.00	
63.43	5.00	2.50	1.67	1.25	1.00		
68.20	4.00	2.00	1.33	1.00			
73.30	3.00	1.50	1.00				
78.70	2.00	1.00					
84.30	1.00						

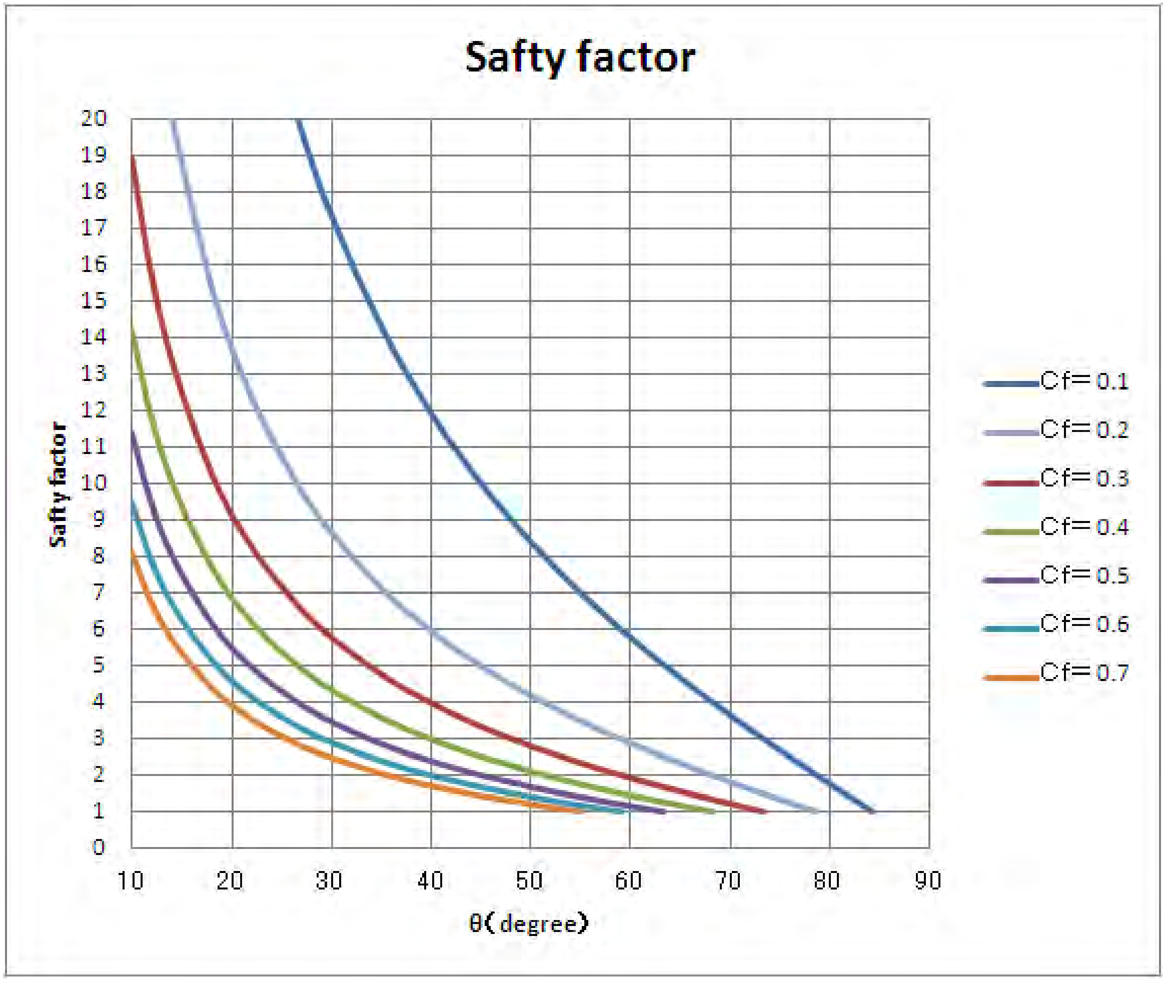


Fig. 3.-2 Preliminary calculation result of the safety factor

Table 3.-1 and Fig. 3.-2 are preliminarily calculated results of the safety factor given by Formula (3.-3). Calculation steps of the friction coefficient Cf (0.1～0.7) and the load direction θ (θ≧10° and 1 ≦ the safety factor ≦20) are given as shown on the table. Usual step level is at Cf ≦ 0.1 and θ = 10 ～ 30 °.

3．4 Summary of Chapter 2 and 3

①The roller tread concave arc angle of the evaluation formulas is 180 degree.
②The formulas are based on an assumption that the contact surface is at its extreme location.
③The formulas are obtained through very logical and sensible approach.
④Eventually the formulas are highly reliable.
⑤An effect of the contact surface friction has to be considered in the gate operation load.
⑦Uncertainty of θ, Cf, contact surface property etc. may cause the incidental element.

４．Study on examples of roller's running off its rail phenomena

Example １：Roller movement power at a start of roller running

（1）Calculation formula and explanation of the case

Sketch a of Fig. 3.-1 corresponds to a state at a start of roller running and a formula of the roller movement power at this state is assembled according to the roller configuration shown on Fig. 4.-1. The roller width left end on the figure coincide with the roller loading point i.e. the contact point. Right hand side of the figure shows a tangential component and a load direction component of a vertical component of movement of a point on the rotation plane including the contact point. The roller movement power is given by formula (4.-1) accordingly. This formula equals Formula (3.-1) which gives the roller's running off its rail force.

Roller movement power = roller load x tangential component x friction coefficient =
roller load x sin(?) x friction coefficient ························(4.-1)

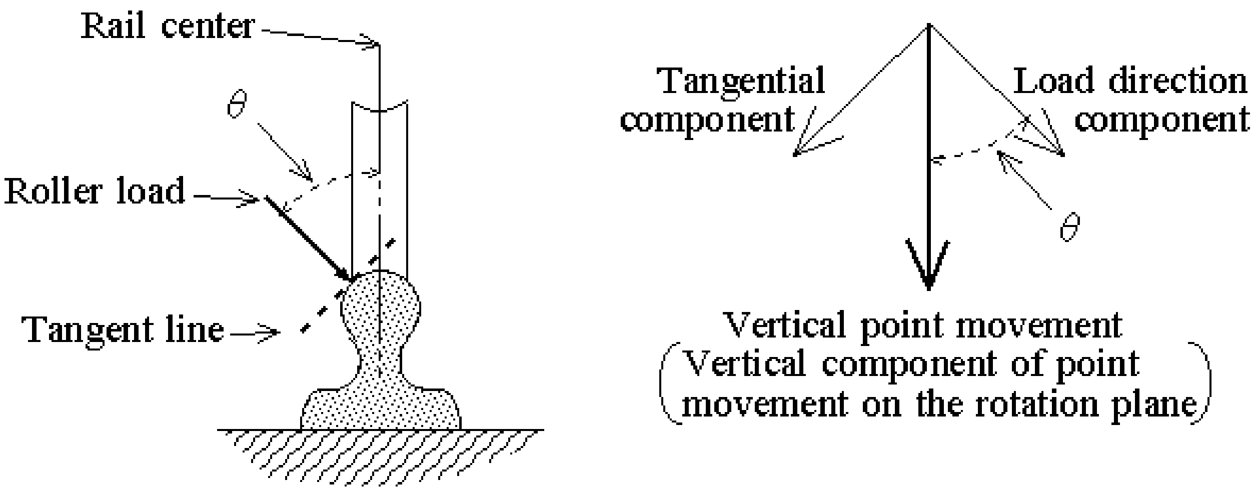


Fig. 4.-1 Roller movement power at a start of roller rotation

Roller movement blocking power equals zero. Accordingly, the roller starts moving toward the rail center with the movement power of formula (4.-1) as soon as the roller starts rotating. Fig. 4.-2 shows a roller moving toward the rail center. The roller load divides into the rail head component force and the tangential component force as shown on the figure. Although the rail friction force decreases with the roller moving, the movement is accelerated and the roller gets run off its rail since the increasing tangential component force (blue collar) works as roller movement power. In short, this case corresponds to a start of the roller's running off its rail that suggests that a meeting of the contact surface with the roller width end is a condition for a start of roller's running off its rail.

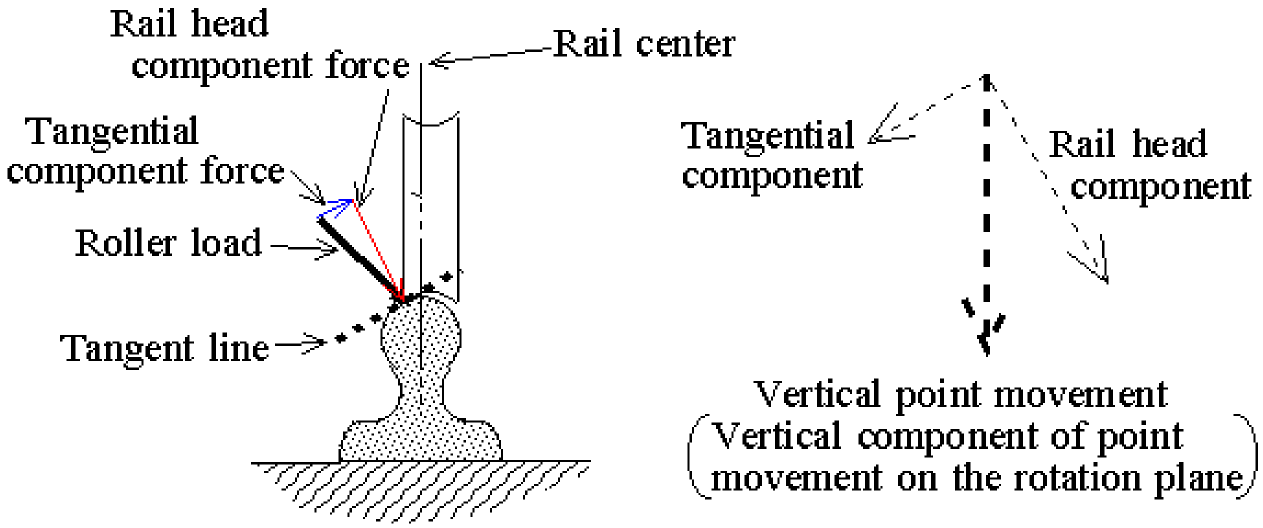


Fig 4.-2 A roller moving toward the rail center

（2）Summary of Example　1

①The roller movement power at a start of roller rotation equals a force to make a roller run off its rail which is given by formula（3.-1'）.
②This case corresponds to a start of roller's running off its rail whose contact surface location coincides with the roller width end.
③The roller's running off starts with a commencement of its rotation and the roller gets run off at a accelerated rate.

Example ２：Stable point of the contact surface

（１）Stabilization of the contact surface location

In case of the roller width of Fig. 4.-1, the contact location coincides with the roller width end. On the other hand, the contact surface of the sketch a on Fig. 3.-1 locates at the inside of the roller width and the roller makes an extremely small movement toward the roller center line with the start of roller running and simultaneously the contact surface moves in reverse direction to the roller movement. Fig. 4.-3 shows the contact surface after its movement. The roller load divides into the rail head component force and the tangential component force. Although increase and decrease of the friction force needs quantitative consideration since the rail head component force will decrease and the tangential component of the vertical component of point movement on the rotation plane (refer to Fig. 4.-3) will increase, the tangential component force (blue collar) will increase to a large extent and work to block the roller movement and the contact surface location will get stable when the roller movement ceases due to equivalence between the friction force and the blocking power.

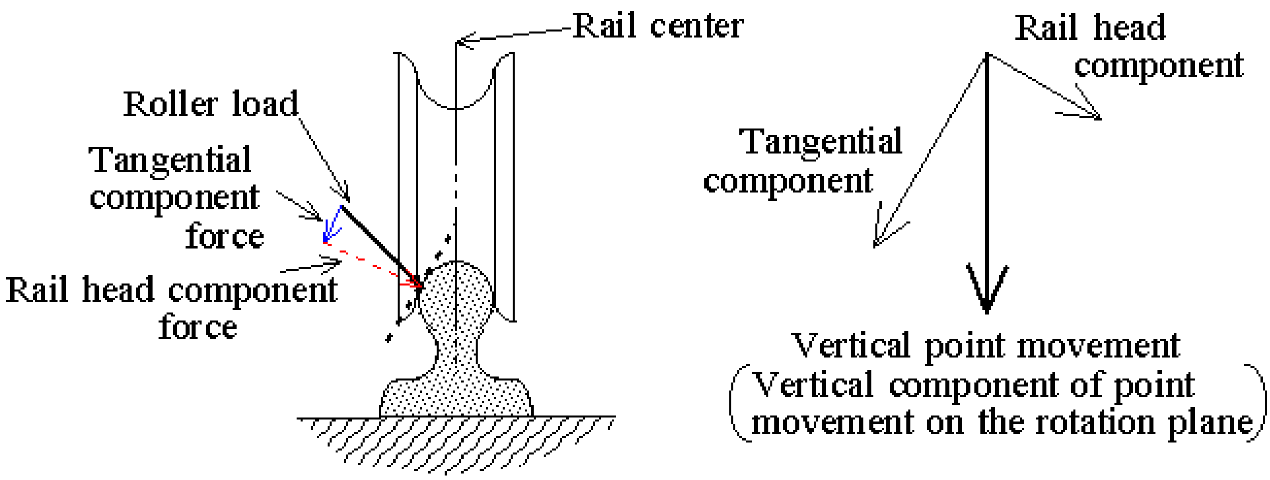


Fig. 4.-3 The contact surface movement toward outside

（２）Formula of stable condition

Fig. 4.-4 is exactly same to Fig. 4.-3 except β and θ are added. θ (entry angle of the roller load) is defined on Sketch a of Fig. 3.-1. Quantitative items indicated on the figure are functions of β, θ and the friction coefficient as given by following formulas.

Tangential component force = roller load x sin (β - θ)

Rail head component force = roller load x cos (β − θ)

Tangential component (of vertical point movement) = sin (β)

Accordingly,

Roller movement power =
rail head component force x tangential component x friction coefficient =
roller load x cos ($\beta - \theta$) x sin (β) x friction coefficient ············(4.-2)

Movement blocking power = tangential component force = roller load x sin ($\beta - \theta$)···(4.-3)

As the roller movement power equals the movement blocking power when the contact surface stay at its stable point, following formula holds.

Roller movement power - movement blocking power = 0 ··········(4.-4)

The formula of stable condition is obtained after (β - θ) is set to $\Delta\beta$ = contact surface travel and formulas (4.-2) and (4.-3) are inserted into formula (4.-4).

$$\sin(\Delta\beta + \theta) \text{ x friction coefficient} - \tan(\Delta\beta) = 0 \quad \cdots\cdots\cdots\cdots (4.\text{-}5)$$

Let left-hand side of formula (4.-5) be set to F ($\Delta\beta$), and the formula be denoted by (4.-6).

$$F(\Delta\beta) = \sin(\Delta\beta + \theta) \text{ x friction coefficient} - \tan(\Delta\beta) \quad \cdots\cdots\cdots\cdots (4.\text{-}6)$$

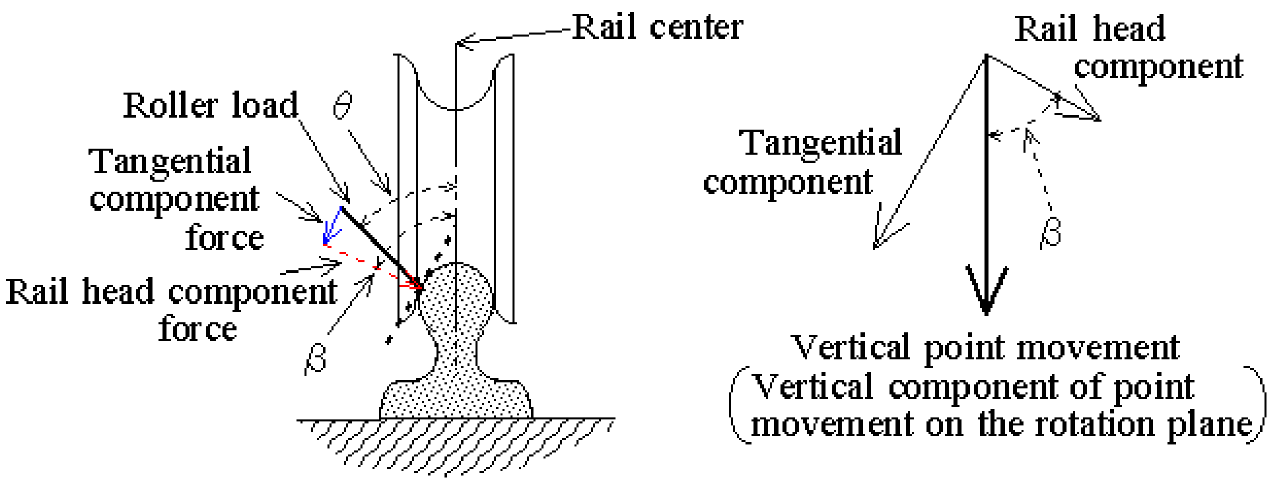


Fig. 4.-4 Formula of stable condition

（3） Numerical calculation

（3－1）Values of function F（Δβ）

Fig. 4.-5 shows F（Δβ）value values versus Δβ which was calculated for a combination of the friction coefficient and the entry angle of roller load θ（°）shown on Table 4.-1. Following findings are obtained from the figure.

①F value simply decreases in all cases i.e. block power increase> movement power increase.
②The less the friction coefficient, the more F value decrease i.e. rapid block power increase.
③The less the entry angle（θ）, the more F value decrease i.e. rapid block power increase.

（3－2）Solutions of the stable condition formula

Table 4.-2 and Fig. 4.-6 show the solutions of stable condition formula（4.-5）of a combination of the cases shown on Table 4.-1. These values correspond to the points where F value curves on Fig. 4.-5 cross the abscissa axis i.e. a stable point（Δβ）of the contact surface. Following findings are obtained from the figure.

（3－3）Amount in % of roller movement power and blocking power

Formulas（4.-2）and（4.-3）are converted to formulas of % display corresponding to β shown on Fig. 4.-4. The % formulas are given as following where 100 % amounts correspond to β of 90 degrees.

Roller movement power in % $=100\times \cos(\beta-\theta)\times \sin(\beta)\div \sin(\theta)$
$=100\times\{\cos(\beta)\ \sin(\beta-\theta)\div \sin(\theta)+1\}$ ……(4.-7)

Movement blocking power in % $=100\times \sin(\beta-\theta)\div \cos(\theta)$ ……(4.-8)

Fig. 4.-7 shows calculated results of the both formulas for 4 kinds of the entry angle of roller load（θ）shown on Table 4.-1. Following findings are obtained from the figure.

①The roller movement power becomes minimum when β equals 90 degree.
②The movement blocking power becomes maximum when β equals 90 degree.

①The less the entry angle（θ）, the sooner the contact surface arrives at the stable point.
②The less the friction coefficient, the sooner the contact surface arrives at the stable point.
③The roller's running off starts when the contact surface arrives at the roller width end in case that the stable point is located out of the roller width.

Table 4.-1 Numerical calculation cases

Friction coefficient		Entry angle θ	
Case mark	Value	Case mark	Value (°)
Ⅰ	0.1	①	11.25
Ⅱ	0.2	②	22.50
Ⅲ	0.3	③	33.75
iv	0.4	④	45.00
Ⅴ	0.6		
Ⅵ	0.8		
Ⅶ	1.0		

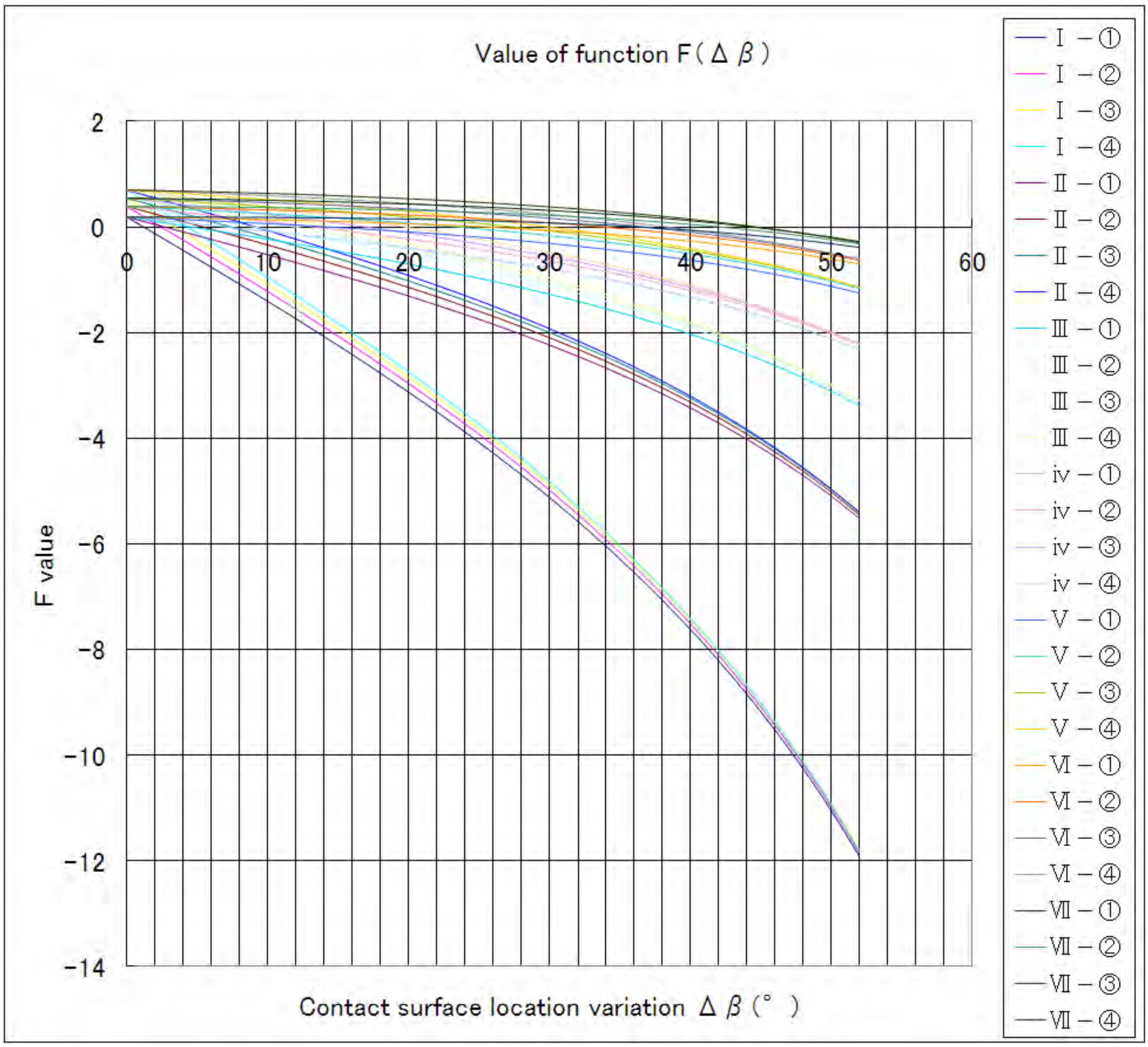
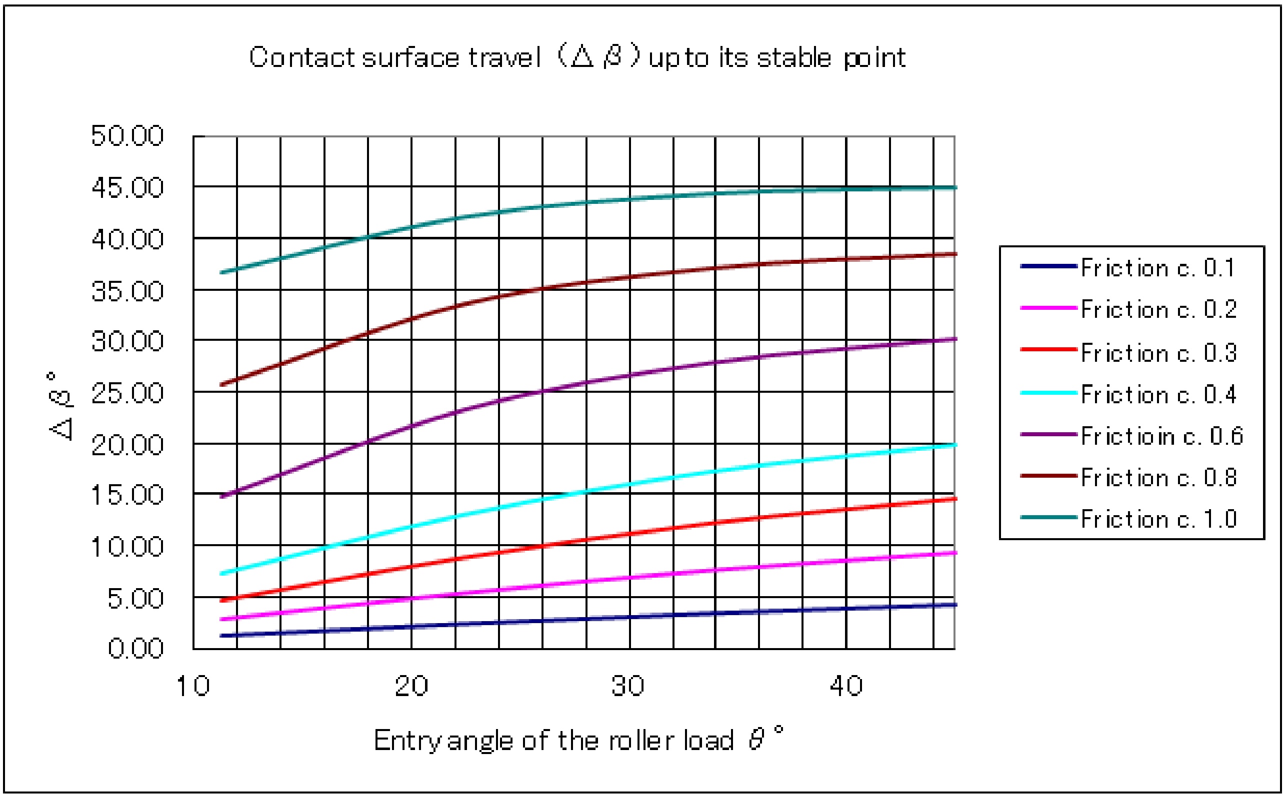


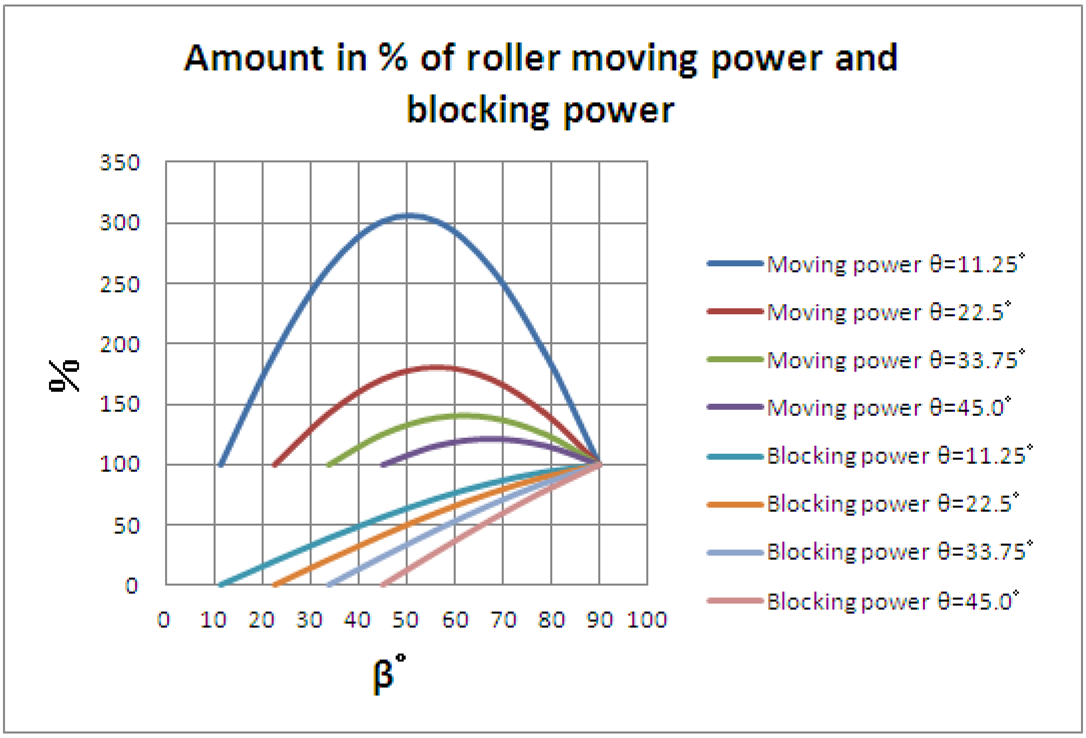
Fig. 4.-5 Value of function F (Δβ)

Table 4.-2 Solutions (Δ β) of the stable condition formula

Entry angle θ	11.25	22.5	33.75	45
Friction c. 0.1	1.24	2.42	3.46	4.34
Friction c. 0.2	2.78	5.33	7.51	9.21
Friction c. 0.3	4.72	8.88	12.15	14.49
Friction c. 0.4	7.25	13.08	17.27	19.91
Frictioin c. 0.6	14.72	23.26	27.78	30.11
Friction c. 0.8	25.67	33.60	37.08	38.48
Friction c. 1.0	36.55	42.09	44.36	44.98



Fit. 4.-6 Solutions (Δ β) of the stable condition formula



Fit. 4.-7 Amount in % of roller moving power and blocking power

（4） Summary of Example 2

（A） Change of F value due to the contact surface location variation

①F value simply decreases in all cases i.e. block power increase> movement power increase.

②The less the friction coefficient, the more F value decrease i.e. rapid block power increase.

③The less the entry angle (θ), the more F value decrease i.e. rapid block power increase.

（B） Stable point of the contact surface

①The less the entry angle (θ), the sooner the contact surface arrives at the stable point.

②The less the friction coefficient, the sooner the contact surface arrives at the stable point.

③The roller's running off starts when the contact surface arrives at the roller width end in case that the stable point is located out of the roller width.

（C） Roller's running off its rail

①The extremely small movement of a roller before the roller's running off completely differs from the roller movement after the start of roller's running off.

②The last stage of roller's running upon its rail is running off its rail.

(D) Roller movement power and blocking power

①The roller movement power becomes minimum when β equals 90 degree.

②The movement blocking power becomes maximum when β equals 90 degree.

5． Image of roller's running off its rail phenomena

A roller's running off its rail never happens in a circumstance where there is no uncertainty of friction and roller load.　Following conclusion is obtained concerning image of roller's running off its rail phenomena.

（A） A scenario of the roller's running off its rail phenomena

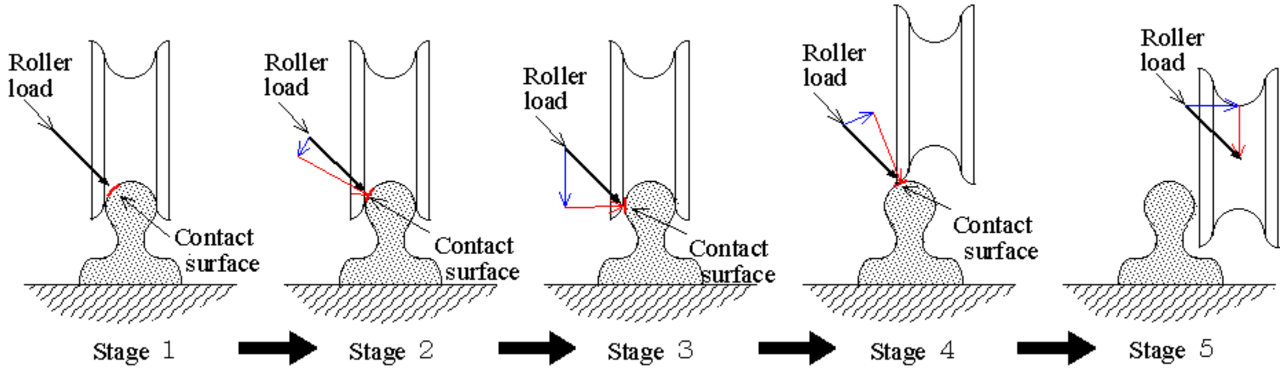


Fig.－９ A scenario of the roller's running off its rail

【Stage 1. Roller in resting】：Roller load is normal to contact surface and heads to rail center.
【Stage 2. Roller in rotating】：Contact surface moves in opposite direction to rail center.
【Stage 3. Running off start】：R. off starts when contact surface arrives at roller width end.
【Stage 4. Running off going】：R. off is going by friction force and roller load（blue）.
【Stage 5. Running off its rail】：Roller on rail top runs off at a blow of roller load（blue）.

Note. ①The contact surface movement likely starts with incidental elements.
②The roller and contact surface movements are supposed to be unsteady.
③The scenario proceeds at accelerated rate from Stage 3 to Stage 5.

（B） The rail contact surface movement

①The contact surface friction force works as a power to move the roller toward the rail center.
②With a roller movement, the contact surface moves in reverse direction to the roller movement and the movement power decreases and the blocking power increases.
③The contact surface movement gets stable at a point of equilibrium between the movement power and the blocking power of the roller movement and <u>the roller's running off will not occur</u>.

（C） Evaluation formulas of the patent application

①The roller tread concave arc angle of the evaluation formulas is 180 degree.
②The formulas are based upon an assumption that the contact surface is at its extreme location.