FE6:

6-roll Sugarcane Mill

Mathematical Model, FEA and its validation by Strain-Gauge measurement

Speaker

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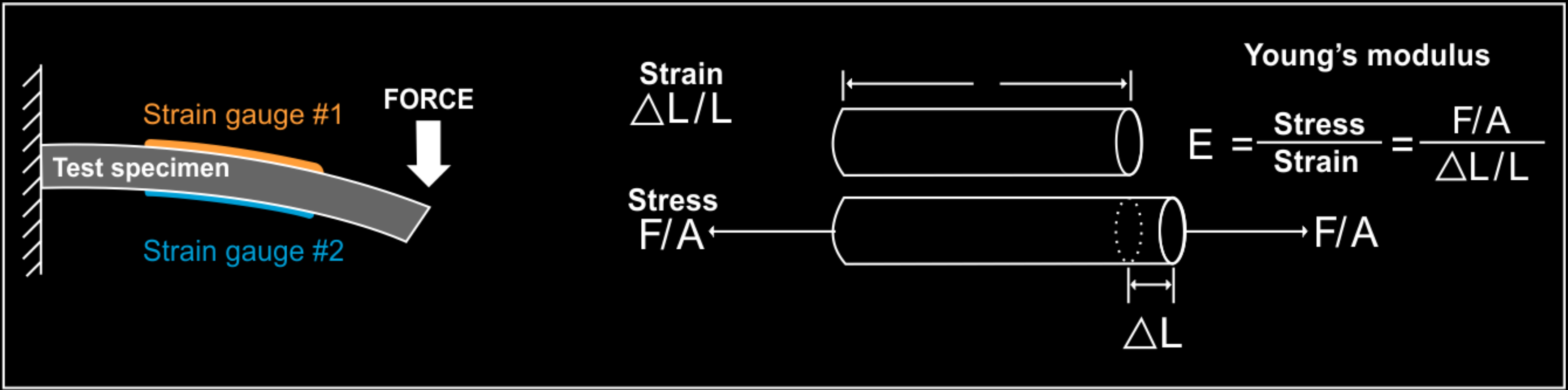

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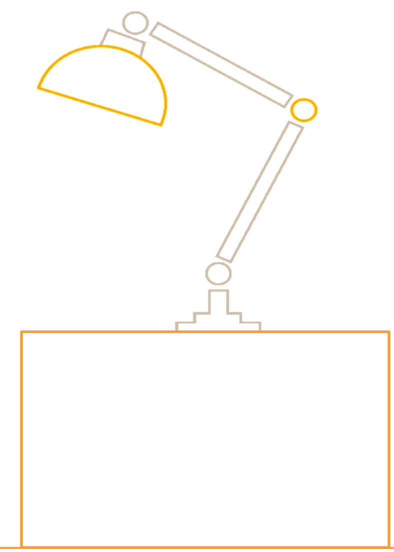
OBJECTIVE OF THE STUDY

TO OPTIMIZE the design of Cane Mill and its components thru:

- Study of machine kinematics & development of advanced mathematical model
- Solving of the model for a selected installation and finite element analysis.
- Validation through field measurement using strain gauge technology.



Application of final model for various sizes of mills

STUDY METHODOLOGY

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1 Development of new mathematical model

2 Solving of the model and FEA

3 Strain-gauge measurement

4 Analysis and validation of the model

5 Application for various mill sizes

STUDY COLLABORATORS

- Isgec Heavy Engineering Ltd, Noida, India

- Automotive Research Association of India,
  a research association of automotive industry
  with Ministry of Heavy Industries, Govt. of India.

- Saraswati Sugar Mills Ltd, Yamunanagar, India
  a 10,000 TCD sugar plant.

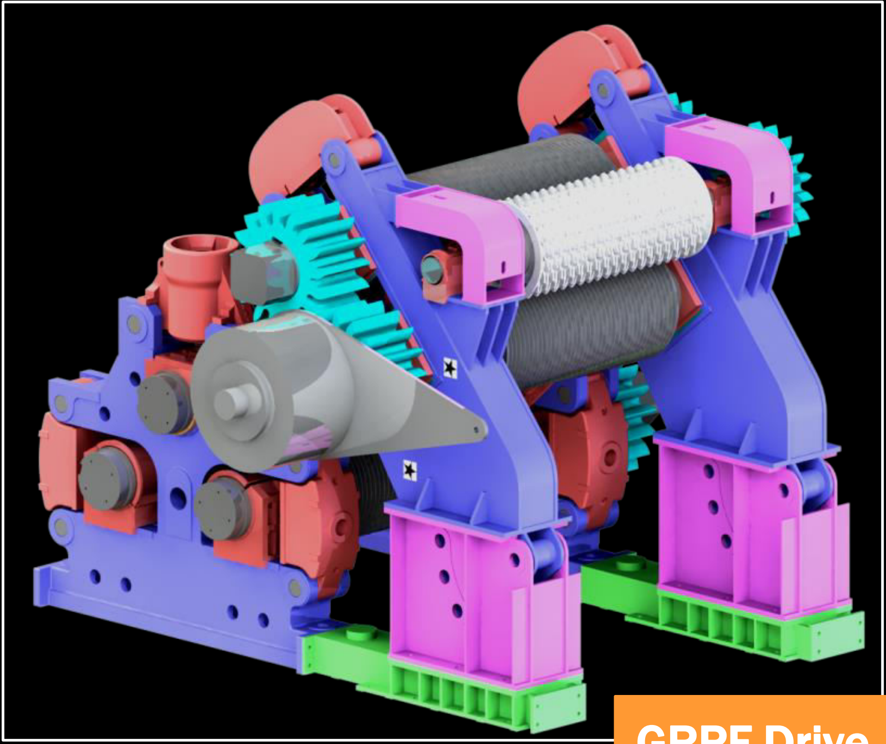
SELECTION OF MILL CONFIGURATION

- Previous work largely for 4-roll mill, lack field validation and ignore bearing friction
- 6-roll configuration chosen for present study as its design is the most challenging.
- 4-roll model results can be derived from 6-roll with relative ease.

3D MODEL

6-ROLL MILL

Mill Drive Side



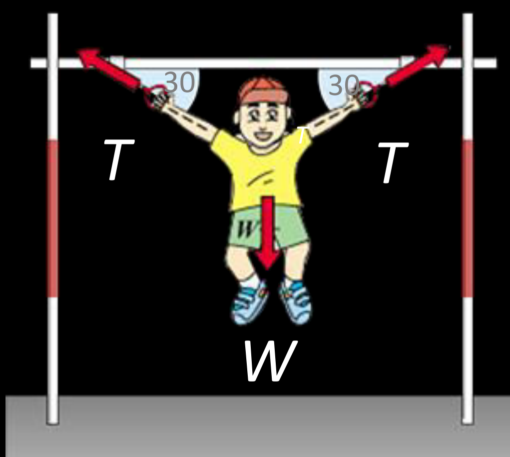
GRPF Drive Side

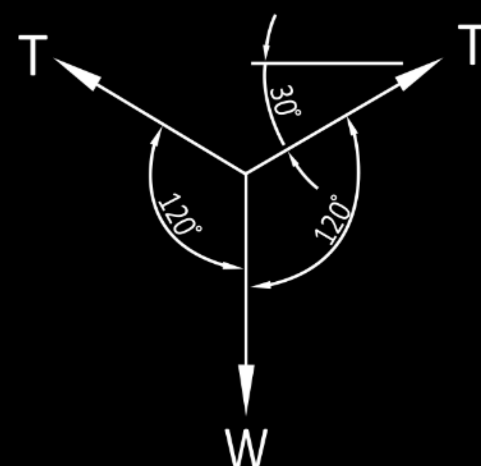
3 rolls of the mill have a common foot mounted electric drive, GPRF has a shaft mounted hydraulic drive

DEVELOPMENT OF A NEW **MATHEMATICAL MODEL**

WHAT IS A MATHEMATICAL MODEL?

Mathematical description of a situation used to understand the machine kinematics and predict its behavior in future.





$$\frac{T}{\text{Sin } 120} = \frac{W}{\text{Sin } 120}$$

$$T = W$$

Typical Mathematical Model

COMPUTATION STEPS

1. Torque sharing between rollers & trash plate
2. Free body diagram of each Mill/GRPF roll
3. Bearing housing couple force diagram
4. Reaction forces on pressure chutes

TORQUE SHARING:
ROLLERS AND TRASH PLATE

Total torque input to mill top roll

$$= \left(T_{tc} + T_{tf} + T_{tr}\right) + \left(T_{fc} + T_{ff}\right) + \left(T_{dc} + T_{df}\right)$$

Subscripts tc, fc & dc represent torque due to cane

Subscripts tf, ff & df represent the bearing frictional torque on top/feed/discharge rolls

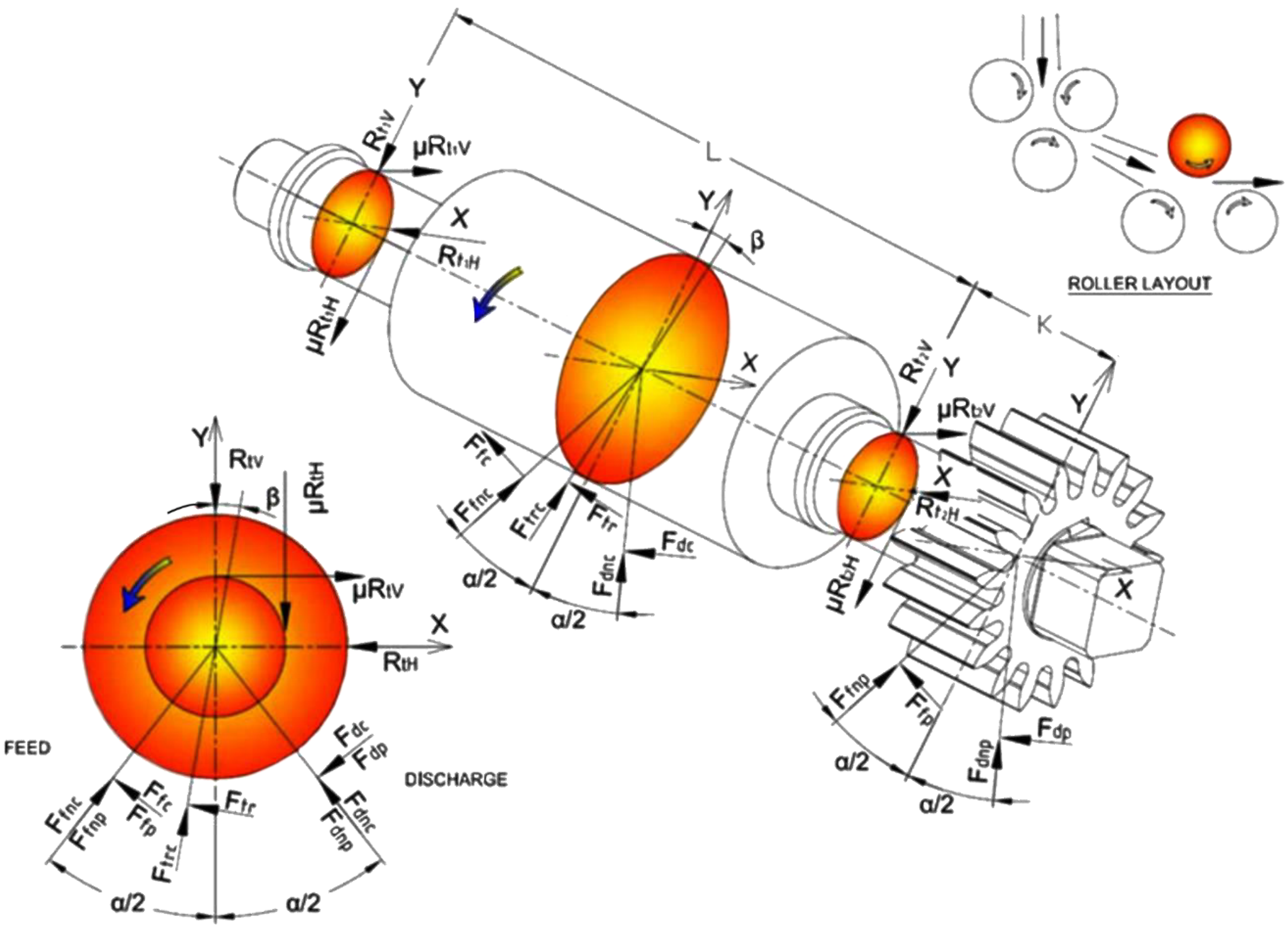
Subscript tr represents cane torque on trash plate.

Total torque input to GRPF bottom roll

$$= \left(T_{gtf} + T_{gtc}\right) + \left(T_{gbf} + T_{gbc}\right) + \left(T_{guf} + T_{guc}\right)$$

Subscripts gt, gb & gu represent GRPF top/bottom & u/feed roll

FREE BODY DIAGRAM OF MILL TOP ROLLER



EQUATION OF MILL TOP ROLLER

$$\boldsymbol{R_{t2h} - \mu R_{t2v}} = \frac{1}{L}.\left[\frac{L}{2}.\left(-F_{fnc}\sin\frac{\alpha}{2} + F_{fc}\cos\frac{\alpha}{2} + F_{Tr}\cos\beta + F_{dnc}\sin\frac{\alpha}{2} + F_{dc}\cos\frac{\alpha}{2} - F_{trc}.\sin\beta\right) - (L+K)\left(-F_{fnp}\sin\frac{\alpha}{2} + F_{fp}\cos\frac{\alpha}{2} + F_{Trc}\sin\beta + F_{dnp}\sin\frac{\alpha}{2} + F_{dp}\cos\frac{\alpha}{2}\right)\right] \quad (14)$$

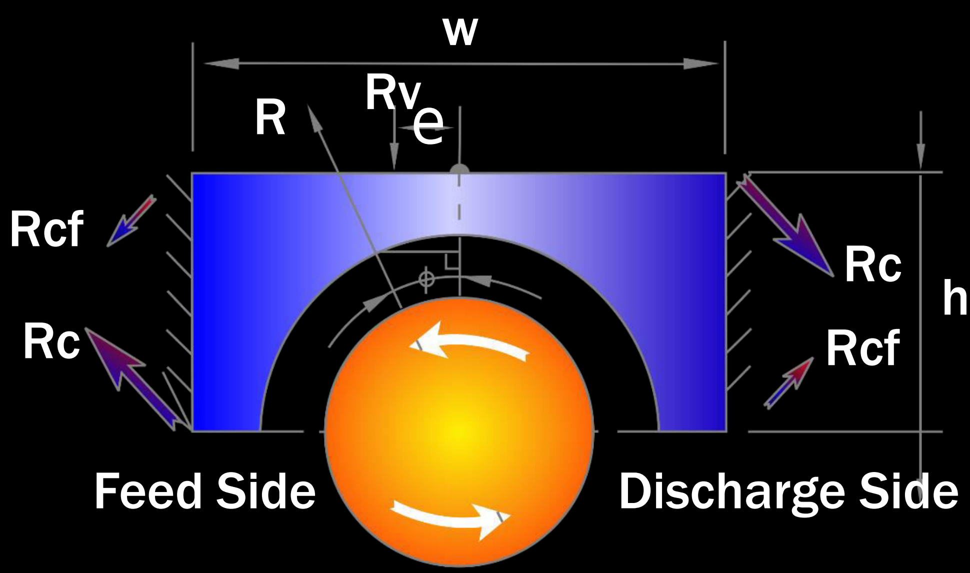
$$\boldsymbol{R_{t1v} + \mu R_{t1h}} = -R_{t2v} + \left(F_{fnc} + F_{fnp}\right)\cos\frac{\alpha}{2} + F_{trc}.\cos\beta + \left(F_{fp} + F_{fc}\right)\sin\frac{\alpha}{2} + \left(F_{dnp} + F_{dnc}\right)\cos\frac{\alpha}{2} - \left(F_{dp} + F_{dc}\right)\sin\frac{\alpha}{2} + F_{tr}.\sin\beta - \mu R_{t2h} \quad (11)$$

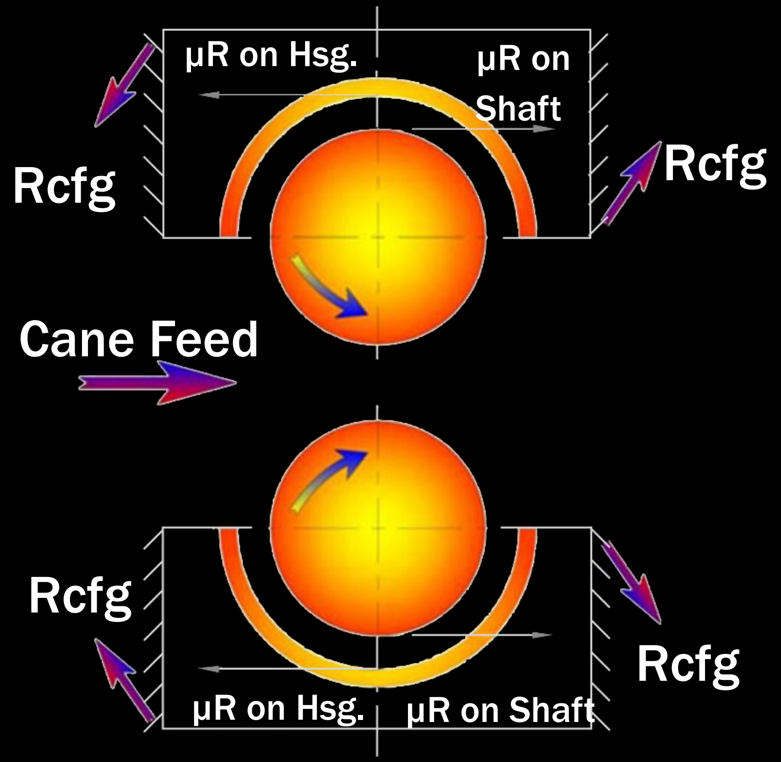
$$\boldsymbol{R_{t2v} + \mu R_{t2h}} = \frac{1}{L}.\left[-\frac{L}{2}.\left(-F_{fnc}\cos\frac{\alpha}{2} - F_{fc}\sin\frac{\alpha}{2} - F_{Tr}\sin\beta - F_{dnc}\cos\frac{\alpha}{2} - F_{trc}.\cos\beta + F_{dc}\sin\frac{\alpha}{2}\right) - (L+K)\left(-F_{fnp}\cos\frac{\alpha}{2} - F_{fp}\sin\frac{\alpha}{2} - F_{dnp}\cos\frac{\alpha}{2} + F_{dp}\sin\frac{\alpha}{2}\right)\right] \quad (13)$$

$$\boldsymbol{R_{t1h} - \mu R_{t1v}} = -R_{t2h} - \left(F_{fp} + F_{fc}\right)\cos\frac{\alpha}{2} - F_{tr}.\cos\beta + \left(F_{fnc} + F_{fnp}\right)\sin\frac{\alpha}{2} - \left(F_{dnp} + F_{dnc}\right)\sin\frac{\alpha}{2} - \left(F_{dp} + F_{dc}\right)\cos\frac{\alpha}{2} + F_{trc}.\sin\beta + \mu R_{t2v} \quad (12)$$

BEARING HOUSING

COUPLE FORCES

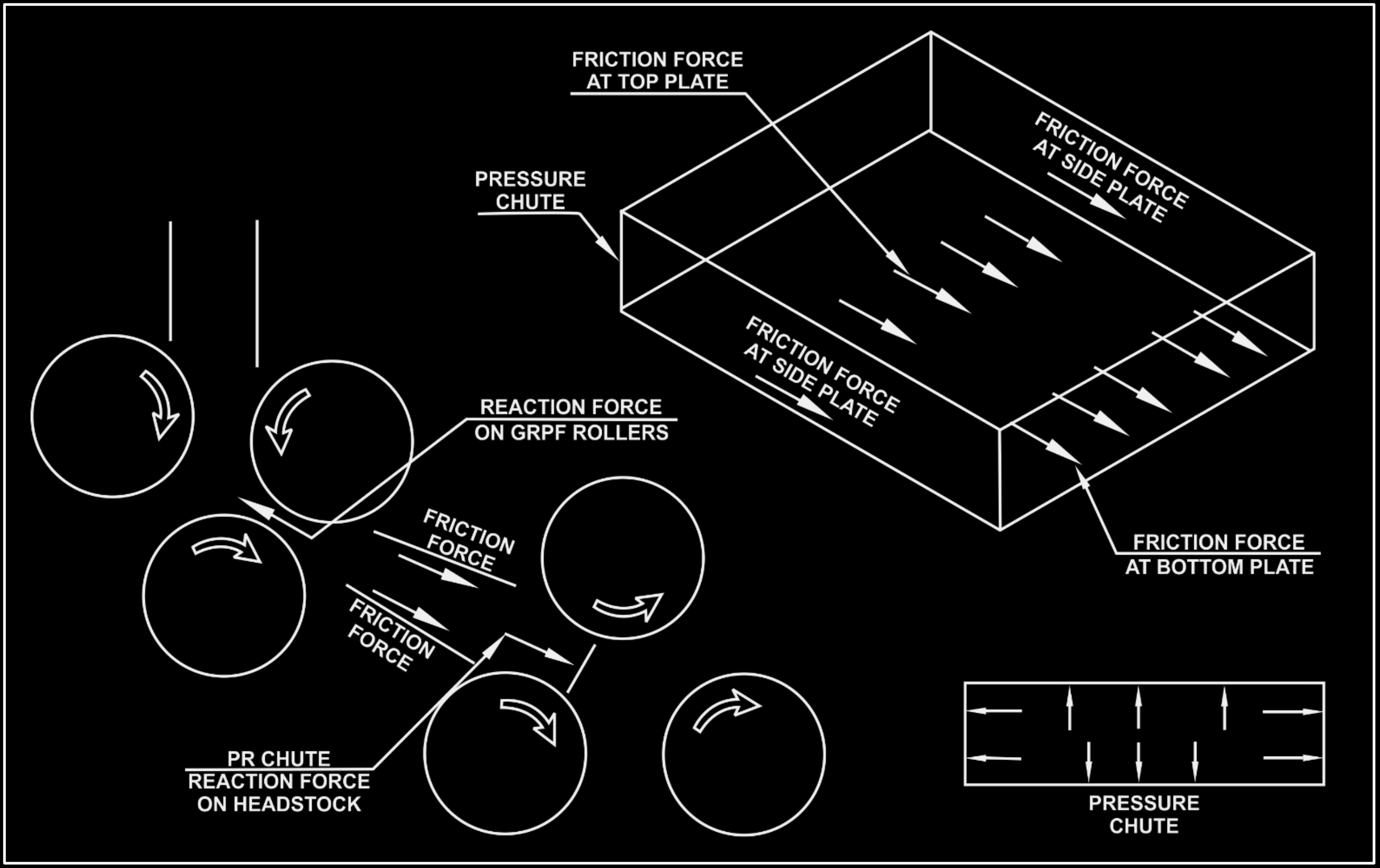




$$R_{cf} = \frac{\text{(Resultant bearing reaction). (Journal radius).} \mu}{\text{square root (bearing width}^2 + \text{bearing height}^2)}$$

e.g. Rcf is couple force on bearing housing due to friction.

REACTION FORCES ON PRESSURE CHUTE



Friction force = Coeff of friction x Pressure on chute x Chute plate area

SOLVING OF THE MODEL

AND FINITE ELEMENT ANALYSIS OF 1980mm (78") LONG, 6-ROLL MILL OPERATING AT 8000 TCD

OPERATING PARAMETERS

Description	Symbol	Unit	Mill	GRPF
Roller dia.	D	mm	915	915
Crush rate	t/hour	t/h	330	
Installed drive	–	kW	650 (DC motor)	315 (Hyd. motor)
Consumed power	P1, P2	kW	365	130
Operating speed	N1, N2	rpm	5.4	6.3
Roll journal dia.	d	mm	460	
Roll journal crs	L	mm	3100	
Top brg housing	wxh	mm	530 x 325	
Hyd. load on top roll (per unit length)	–	t/m	206	–

FORCE/TORQUE DISTRIBUTION

Description	Source	Mill	GRPF
Friction coeff (white metal brg)	Field data	0.06	0.06
% torque for mill rolls (feed / discharge / top)	Field data	24/24/52	--
% torque for GRPF rolls (top / bottom / UFR)	Assumed	--	46/46/8
Force ratio for mill: disch / feed	Field data	7:1*	--
Force ratio for grpf: top / bot	Assumed	--	1:1
Push force in pressure chute	Assumed	171 kN	
Fraction of hydraulic force on trash plate	Field data	0.2 of hyd. load	

*Initial assumption 2:1 corrected to 7:1 after field validation

Model OUTPUT

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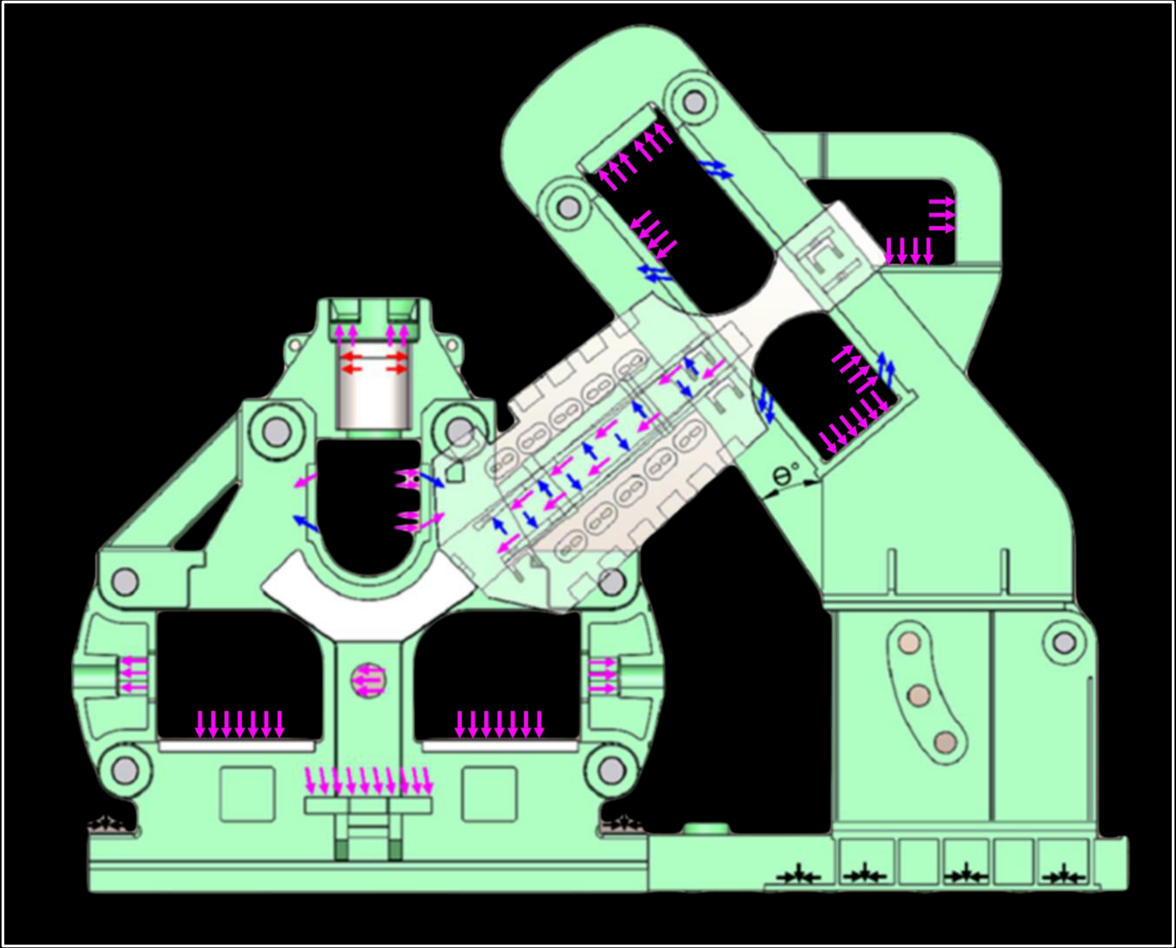
Reaction Forces on Bearing Housing (kN)

Description		Mill roller bearing housing			GRPF bearing housing		
		Top roll	Feed roll	Disch roll	Top roll	Bot. roll	UFR
Drive side	Rh2	1468	27	1395	(-)22	11	44
	Rv2	2255	388	1241	393	331	32
Pintle side	Rh1	847	301	1029	136	338	42
	Rv1	2060	83	1427	457	310	(-)21

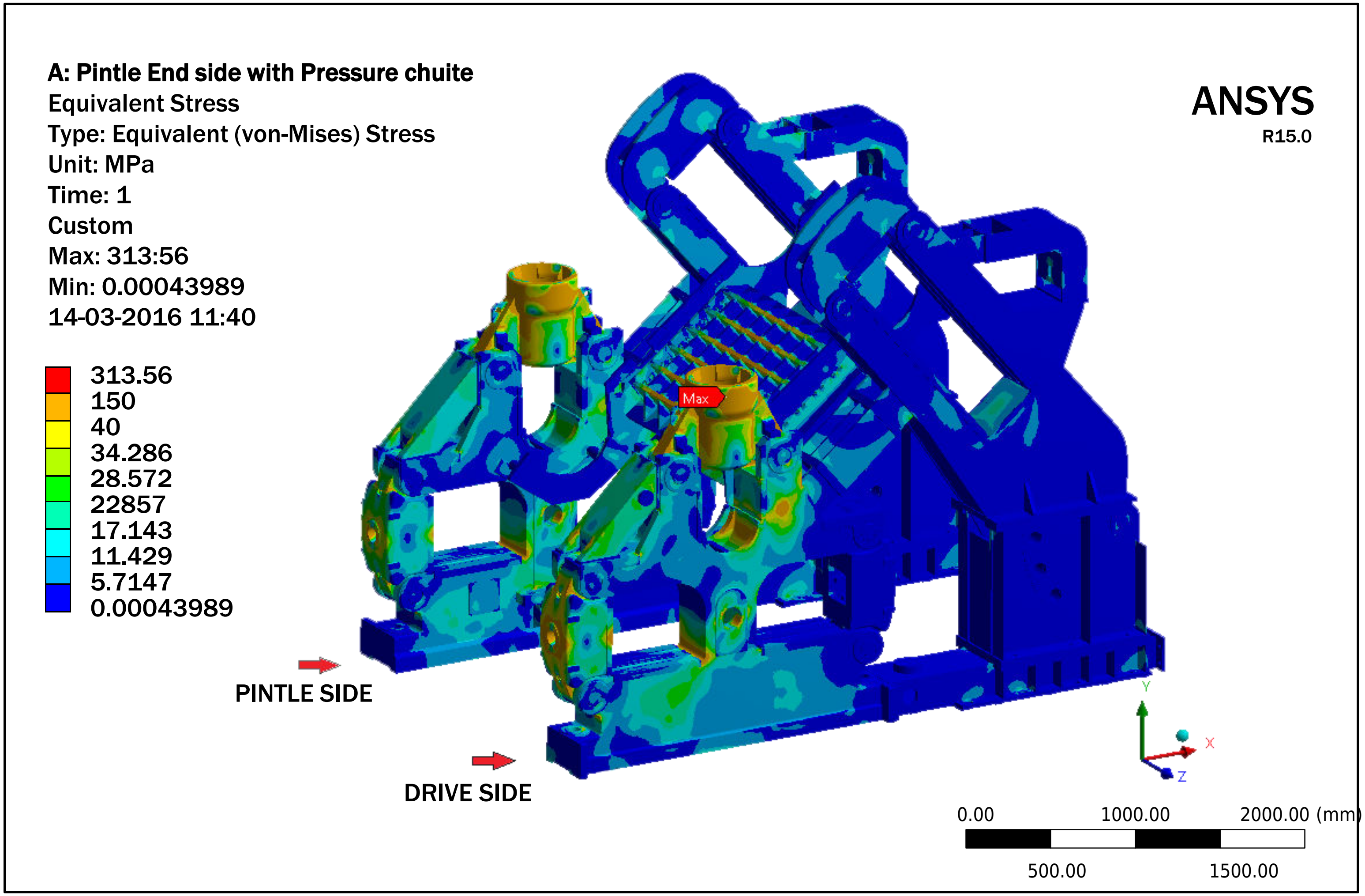
Forces on trash plate, pressure plate and bearing couple (kN)

Description	Trash plate		Pr. chute	Mill hsg	GRPF housings		
	Ftr	Ftrc	Fgc	Rc	Rcf	Rctg	Rcbg
Drive side	25	401	171	446	60	9	7
Pintl side	25	401	171	216	49	11	10

MODEL OUTPUT USED AS INPUT FOR FEA

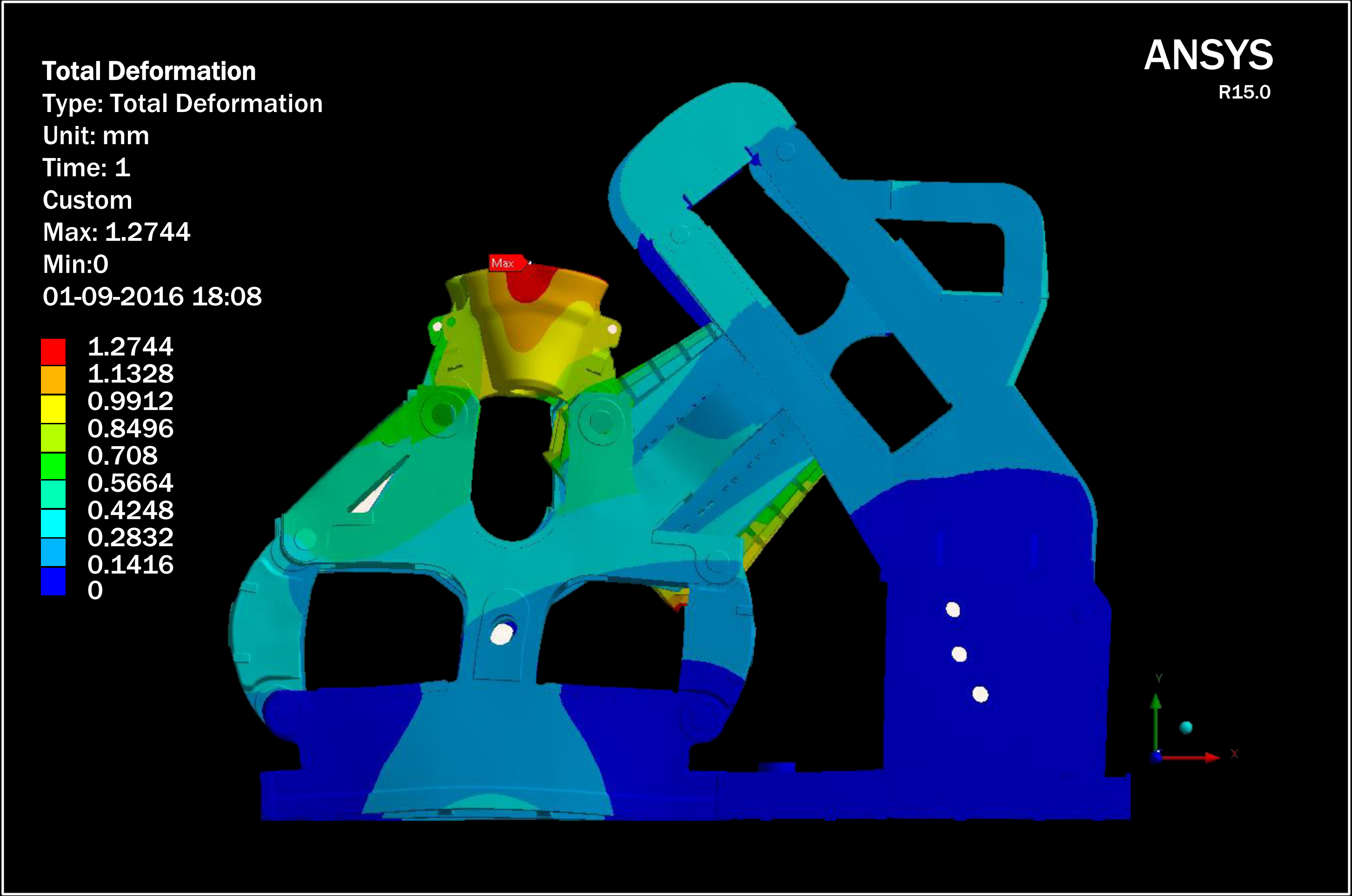


FEA OUTPUT :
STRESS PATTERN



FEA OUTPUT :

DEFLECTION PATTERN

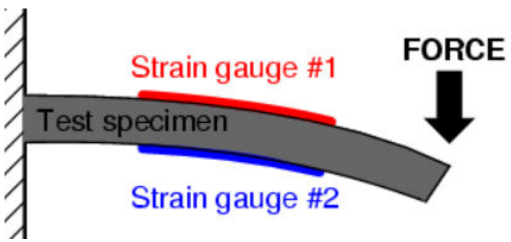


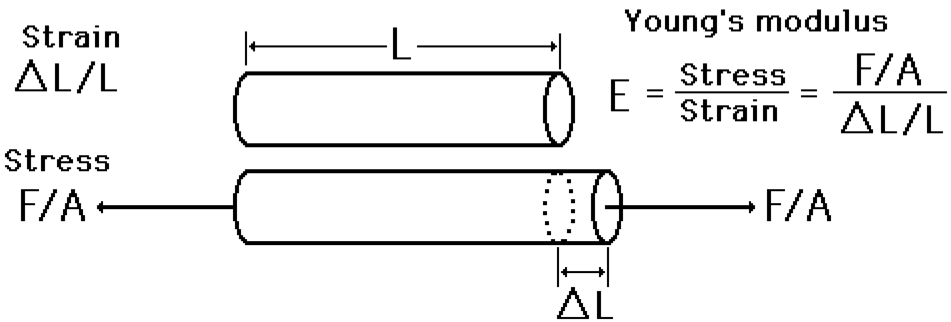
STRAIN-GAUGE MEASUREMENT

ON 1980mm (78”) LONG, 6-ROLL MILL OPERATING AT 8000 TCD

STRAIN GAUGE :

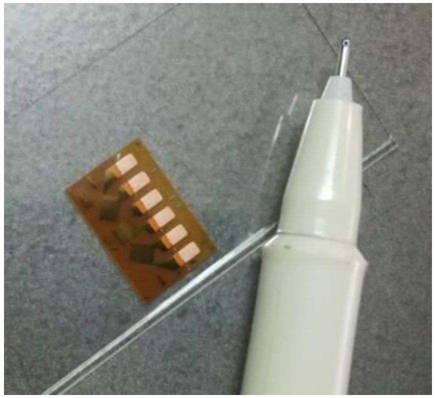
THE SMALL WONDER





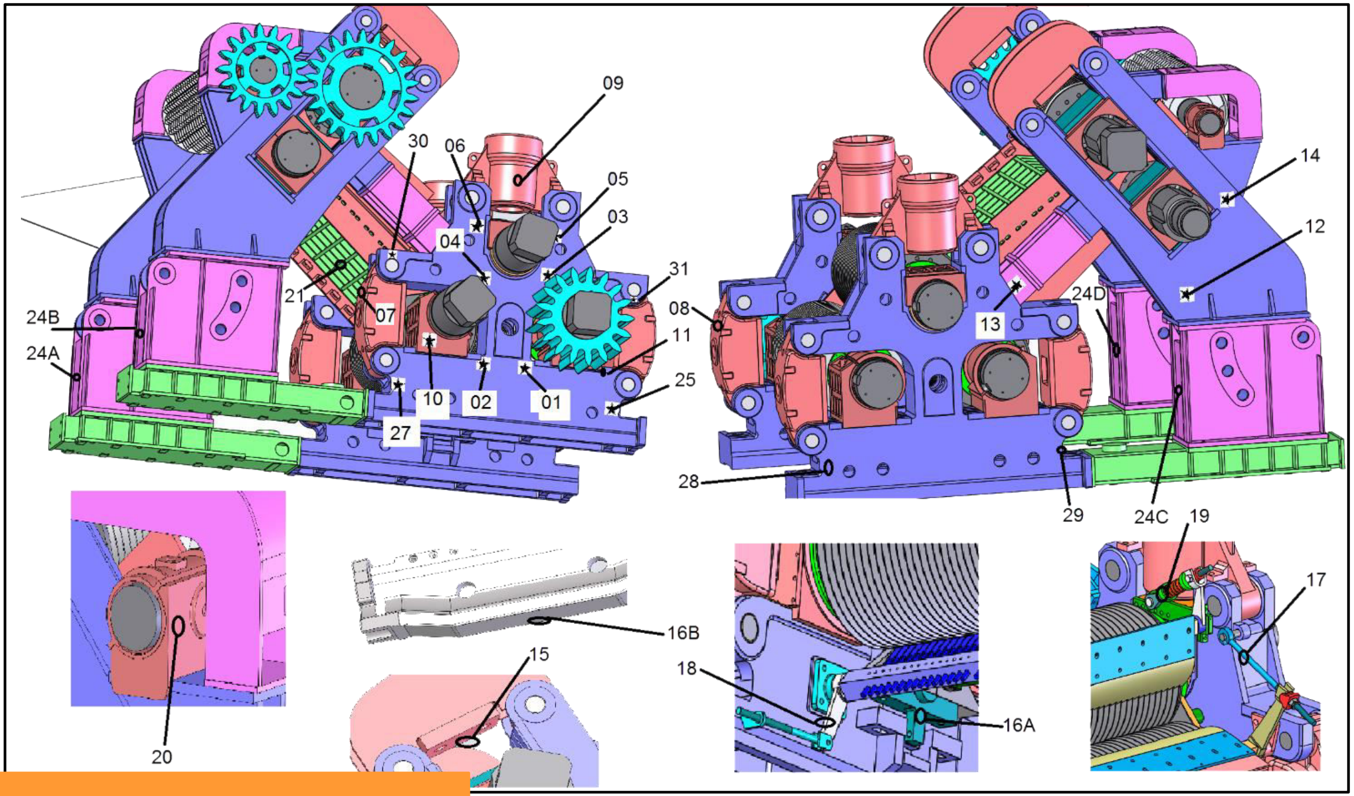
Strain Gauge measures expansion / contraction of surface

- Stress of component having complex geometry can be derived using FE analysis.
- FEA is validated thru strain measurement at various locations of the component under actual operating conditions.



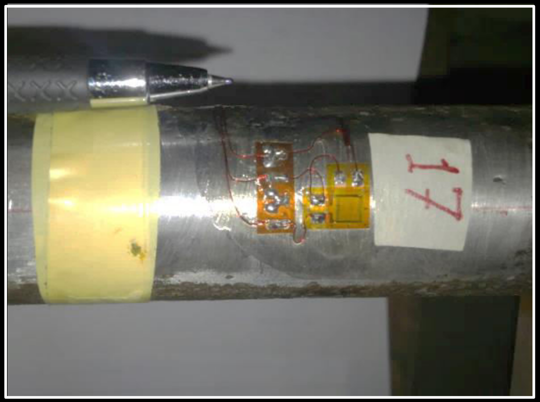
Stress = Measured strain x Young's Modulus

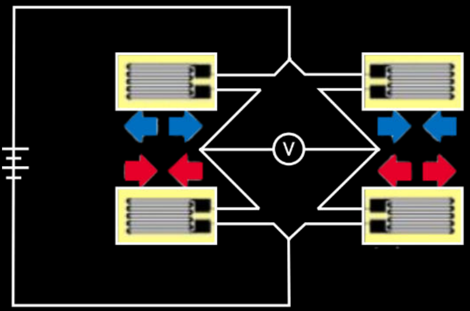
STRAIN GAUGE :
THE SMALL WONDER



32 locations on 6-roll mill used for strain measurement.

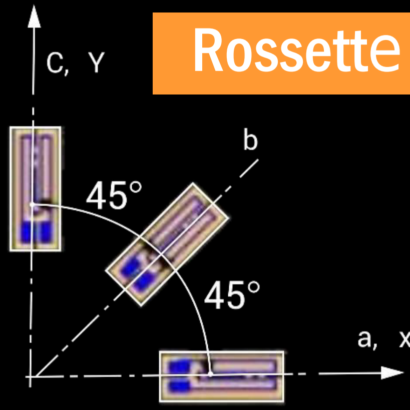
TYPE OF STRAIN GAUGES USED

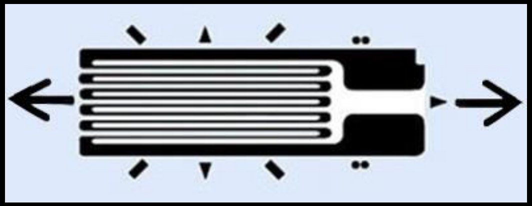




Full Wheatstone Bridge

Rossette





Uni-axial

STRAIN GAUGE

FIXING & PROTECTION

IDENTIFICATION METHODOLOGY

IMPORTANT LOCATIONS

GRPF pressure Chute

Foundation Bolt Reactions

IMPORTANT LOCATIONS

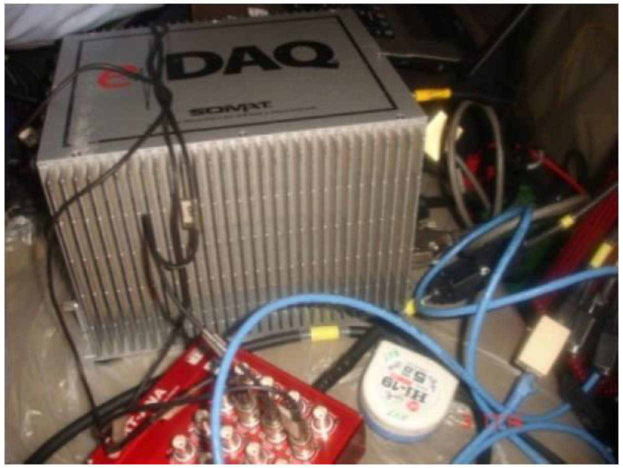
GRPF Top Cap

DATA LOGGING AND ANALYSIS

80-channel eDAQ portable system of Somat (USA) used at 100Hz for data acquisition and continued for 3 consecutive days: 10 hrs on 19 Dec, 10 hrs on 20 Dec, 8 hrs on 21 Dec 2015.

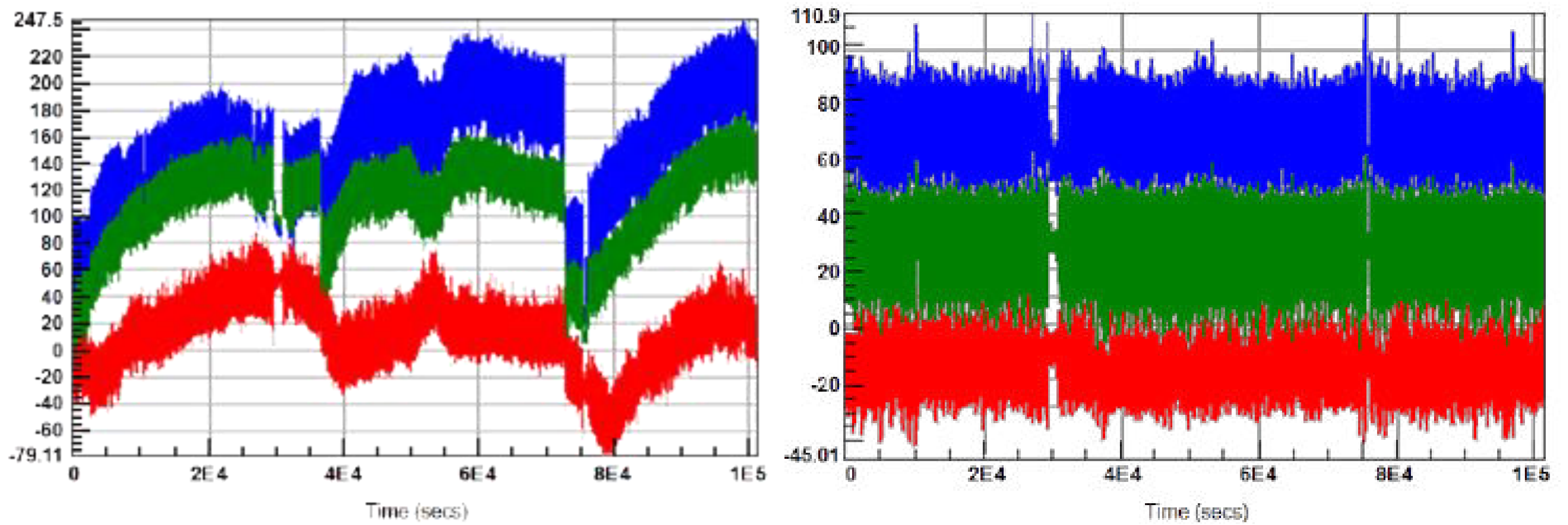
Following Data Acquired

- Strain at 32 locations
- Mill/GRPF roller speed
- Load at mill/GRPF drives
- Top roller lift
- GRPF hydraulic pressure
- Cane crush rate



Data Acquisition System

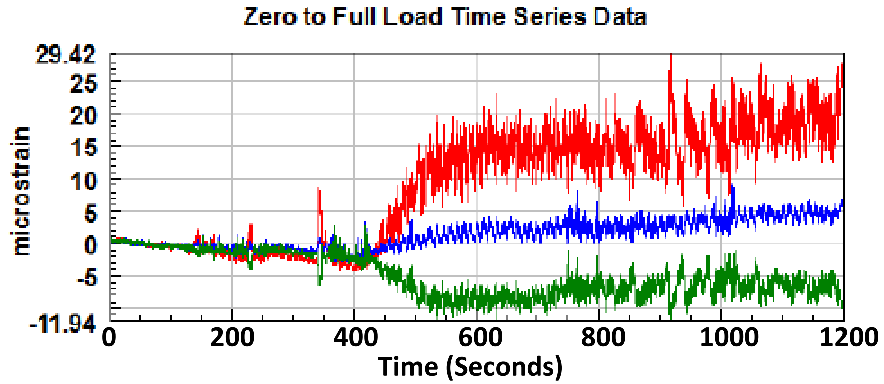
STRAIN GAUGE OUTPUT DATA CORRECTION (TYPICAL)



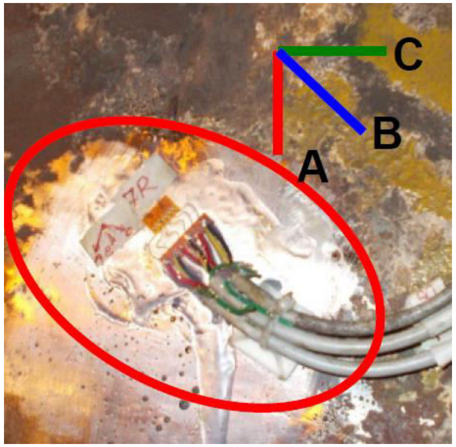
Original Data with drift

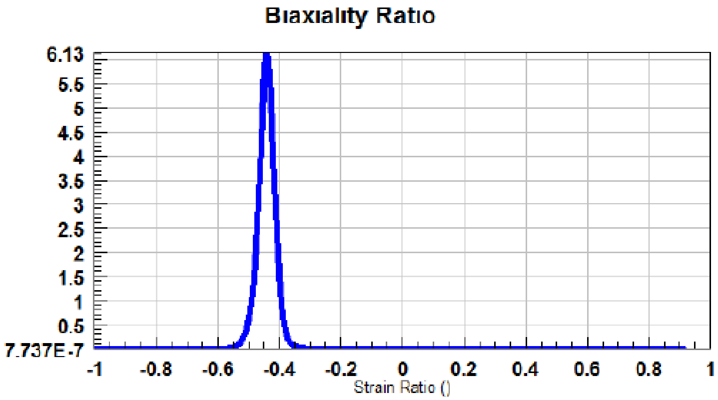
Filtered Data with drift removed

STRAIN GAUGE OUTPUT DATA OBSERVATIONS

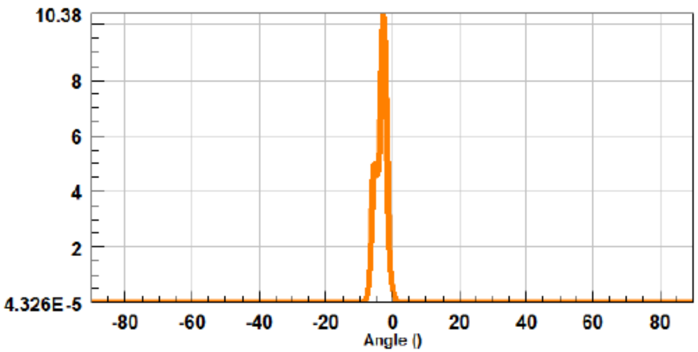


Strain at start of mill (Side cap at feed side)



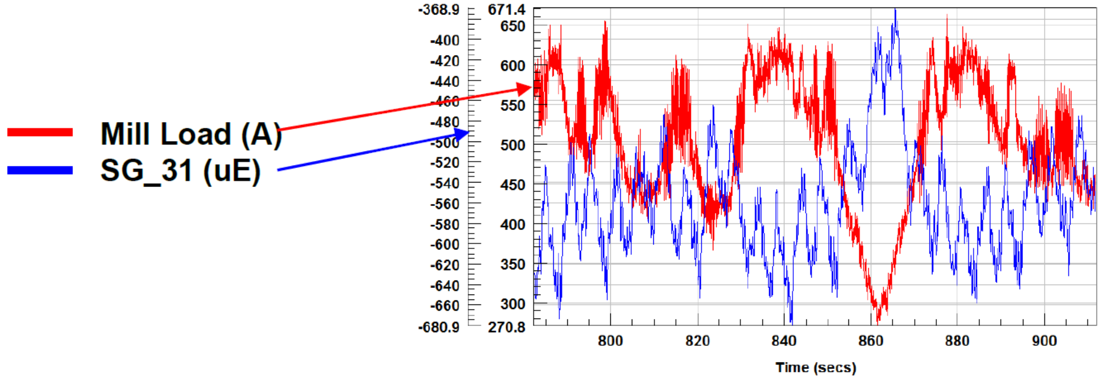


Bi-Axiality ratio



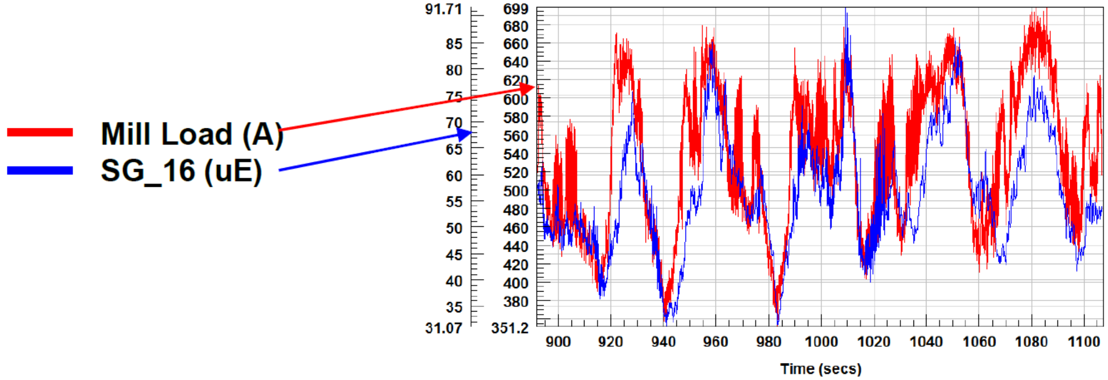
Resultant principal angle

STRAIN GAUGE OUTPUT DATA OBSERVATIONS

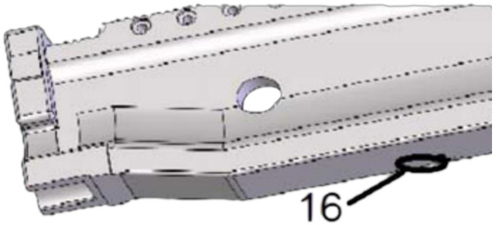


Out of phase data: Mill load Vs strain

Top Pin of Discharge Side Cap



Same phase data: Mill load Vs strain



Turn beam

ANALYSIS AND VALIDATION OF THE MODEL

VALIDATION:
RESULT COMPARISON

Gauge mark no./type		Stress value (MPa)	
		From field measurement	Calculated from FEA model
Gauge fixed at headstock side face			
01	R(+)	34.4	33.6 / 35.7
02	R(+/-)	14.3	16.8 / 18.9
03	R(+)	8.4	8.4 / 9.45
04	R(+/-)	5.4	9.8 / 10.5
Gauge fixed at side caps			
07	R(+)	0.6	1.1 / 1.3
08	R(+)	23.7	27.3 / 29.4
Gauge fixed at mill hydraulic top cap			
09	R(+/-)	8.1	12.6 / 13.6
Gauge fixed at mill bottom roller bearing housing			
10	R(-)	1.8	1.2 / 1.4
11	R(-)	15.9	17.2 / 18.4

VALIDATION:
RESULT COMPARISON

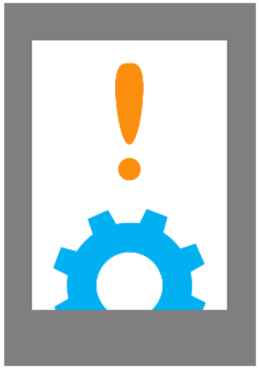
Gauge mark no./type		Stress value (MPa)	
		From field measurement	Calculated from FEA model
Gauges fixed at GRPF side face			
12	R(+/-)	7.9	7.3 / 7.8
13	U(+)	2.9	4.6 / 5.5
Gauges fixed at turn beam			
16B	U(+)	11.1	12.6
Gauges fixed at GRPF Stools			
24A	U(-)	3.4	1.9 /2.1
24B	U(-)	1.2	2.5 / 2.7
Gauge fixed at headstock base			
Mill drive side (discharge)			
25	R(+/-)	2.1	10.5 / 12.6
Mill drive side (feed)			
27	R(+/-)	2.31	1.9 / 3.1

OBSERVATION ON FIELD VALIDATION

- Initially assumed feed to discharge ratio of 2 corrected to the field result of 7.
- Initially assumed value of 80 t/m load on GRPF roller corrected to field result of 26 t/m.
- Frictional power loss at the mill and GRPF bearings is 20% and 10% of consumed power.
- Field measured data differs widely from FEA in some cases, particularly at top cap and fdn bolts.

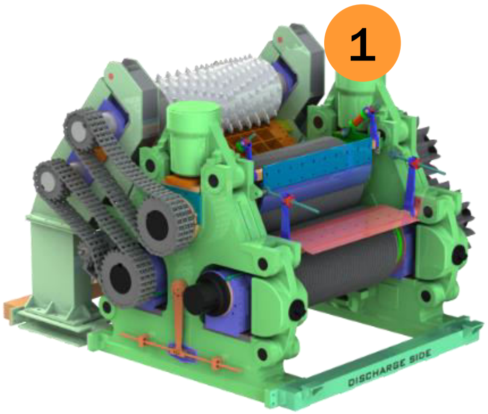
CONCLUSION

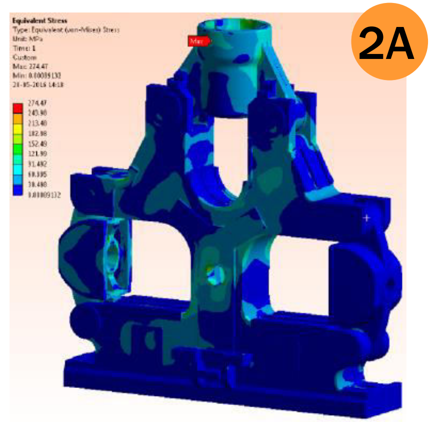
- A new mathematical model of a 6-roll mill has been developed which also takes into account friction loss at mill roller bearings.
- The model was prepared and solved for a 1980 mm size mill based on field measured data for force and torque distribution.
- The model was fine tuned on the basis of comparison of FEA and strain gauge data.

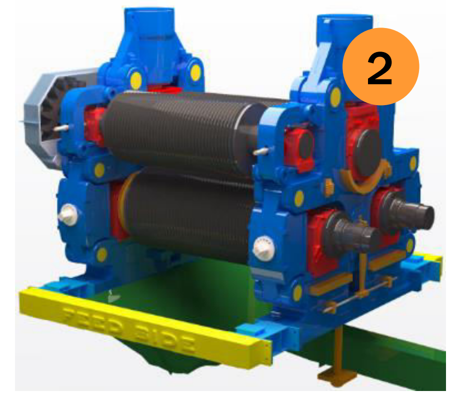


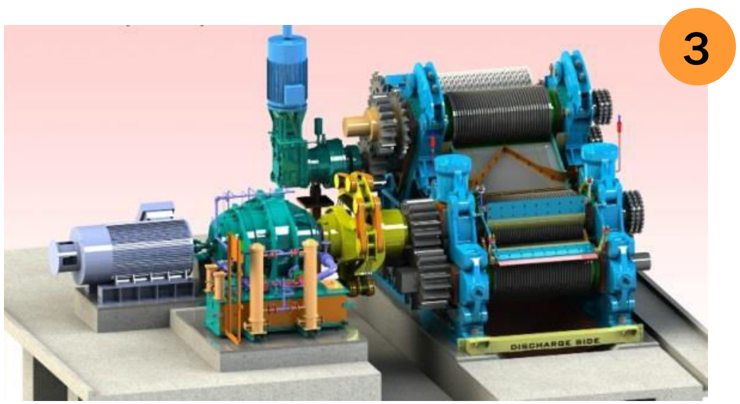
APPLICATION OF STUDY

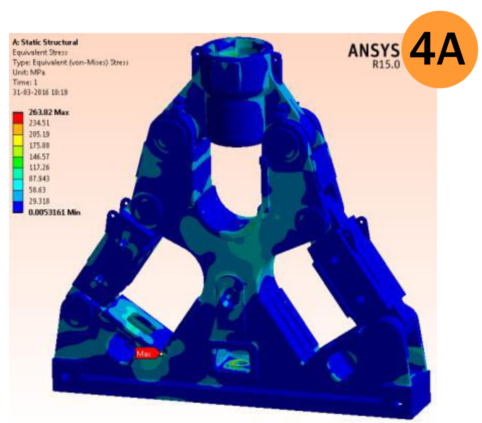
Models developed for different configurations to engineer sturdy design of 2030 mm to 2790 mm (80” to 110”) long mills

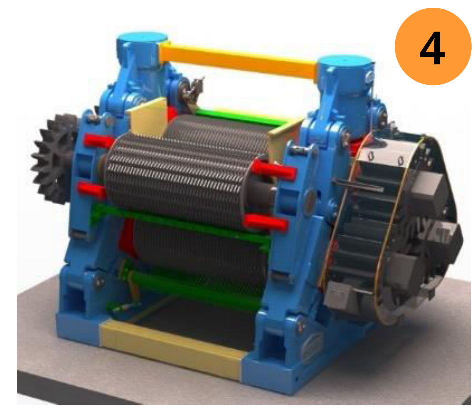












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