Design and analysis of TUNDISH TRANSFER CAR PALLET

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ABSTRACT

Molten metal handling is the high end safety process. In which molten metal is at or above 1200 degree Celsius and some accident at this level will leads to loose of life and permeant damage of plant equipment (asset). To focus on human and asset safety we are here decided to design and analysis of Tundish Transfer Car Pallet. In process of continuous casting it is required to stop casting in between full of molten metal condition. Then need to take the Tundish to from casting platform to Tundish preparation area to make it empty. In between the process of this travel need Tundish transfer car. The tundish transfer car is design for static condition with full load and dynamic condition while Tundish loading the car from crane to pallet and unloading from pallet to crane. Above mentioned condition are the optimum design case happing with the total process. This led to the development of a finite element (FE) model of the full scale experimental configuration which was used to conduct advanced simulations. By comparing the results between the calculous and FEA model we get final optimized result solution. That will decide the final tundish transfer car pallet design.

Index Terms—*Tundish, Tundish Car, Continuous Casting Machine (CCM), Static analysis, Dynamic analysis, impact loading.*

I. INTRODUCTION

A. Continuous Casting Machine (CCM)

Continuous casting of steel is a process in which liquid steel is continuously solidified into a mould of metal. Depending on the strand distance, these semi-finished products are called slabs, blooms or billets. Steel billets has a square cross section with one side normally 150-200 mm or less. It is a feed material for rolling of steel in light section mills, bar mills, and wire rod mills. Steel billets are also used in forging, pressing of certain standard products. This type of process requires great control of operation in order to produce sound and continuous billets. The process can be separated into a number of steps starting by pouring the liquid metal steel from the steelmaking furnace into the ladle, where the steel chemistry is being adjusted in secondary steelmaking, then pouring into the manifold (tundish), and from the manifold (tundish), into the casting mould. Solidification of steel starts in the copper casting mould tube by indirect cooling, an area which was subjected to many studies. From mould the red hot billet undergoes secondary cooling with water sprays system.

B. Tundish

In the process of continuous casting, to transfer of molten steel from a ladle to the mould, an intermediate vessel, called a tundish, is used. A tundish is a rectangular big end up refractory bricks open container which may have a refractory brick cover on the top. The tundish bottom has one or more holes with slide gates unit or stopper rods mechanism for control over the metal flow. It is used to feed liquid steel into the copper moulds tube of a continuous casting machine, so as to avoid wastage and give a smoother flow. The tundish being a reservoir of the liquid steel ensures the feed of the liquid steel to the continuous casting machine during the exchange of steel ladles, thus acting as a buffer or reservoir of liquid steel. It smoothens continuous flow, regulates steel feed rate to the mould and cleans the metal.

The tundish is play role to deliver the liquid steel to the moulds evenly and at a designed rate and temperature without causing contamination by ingredients. The number of moulds is normally 1-2 for a slab casting machine, 2- 4 for a bloom casting machine and 2- 8 for a billet casting machine. The delivery rate of liquid steel into the mould is held constant by keeping the depth of the moulten steel in the tundish constant. Since the tundish act as a reservoir of liquid steel during the period of ladle change periods and since it continues to supply liquid steel to the moulds when the incoming liquid steel has stopped due to ladle change, it makes the sequence casting by a number of ladles feasible.

C. Tundish Transfer Car

Tundish transfer car is a vehicle to carry Tundish form maintenance area to plant or vice-versa. For preparation of Tundish or preheating, it need to carry to the maintenance room. As the weight is too high (45 Ton), it required transfer vehicle. This transport can be done by overhead crane or by ground skidding. At the case were overhead crane access is not possible, mostly preferred to go with rail and car option.

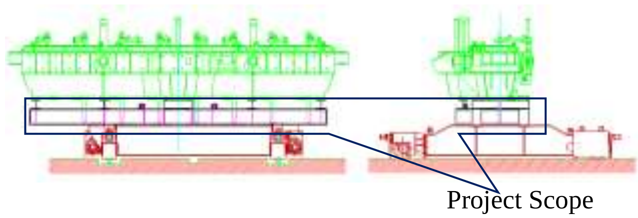


Fig:1 Tundish Transfer Car

As marked in above image, area of project scope. Project's most focus on mounting frame of Tundish. It is bolted section in between of Tundish car and Tundish. Were all forces of Tundish, transfer to mounting frame and mounting frame to Tundish car wheel.

D. Project Scope

As shown in Fig.1, the Tundish mounting frame is the study area. In which the frame is made up of plate and section beam. On which Tundish is located at 3 point and rest at 5 surfaces. Forces of this area is transfer as following path,

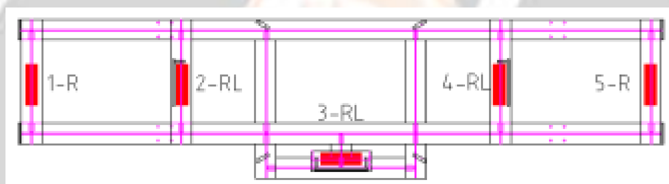


Fig:2 Location and Resting point on pallet

As shown in above figure resting point (1-R and 5-R) plus location and resting point (2-RL, 3-RL, 4-RL). Out of this 5 points three point will carry whole load of Tundish. So the total load will divided in 3 parts and which considered effective load for every individual location.

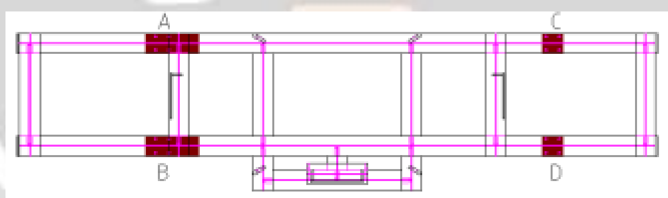


Fig:3 Resting of Pallet on Tundish car

Above fig. shows the resting point A,B,C and D are the fixture resting point, on which fixture frame rest and bolt on Tundish car.

E. Load Condition

Following chart shows load condition

TABLE1
LOADS CONDITION OCCUR

	Load Case 1	Load Case 2	Load Case 3
Tundish	No Tundish	Empty Tundish	Full Tundish
Exceptional working case	--	Loading / Unloading	Loading and Impact

F. Parameter

Loads characteristics for tundish and tundish car are given in below chart.

TABLE2
LOADS PARAMETERS

Sr. No.	Description	Parameter
1	Weight of Tundish Car	14500 Kg (14.5 T)
2	Weight of Mounting Frame	7000 Kg (7 T)
3	Weight of Empty Tundish	45000 Kg (45 T)
4	Weight of Full Tundish	90000 Kg (90 T)
5	Crane Capacity of To Lift Tundish	150 T
6	No of resting Point on Frame	5 Nos
7	Expected Safety Factor	1.5
8	Tundish Transfer Car Speed	20 M/Min
7	Drive Break	Induction Motor with Break

G. Joints and Contact

All frame joints are welded with full butt joints. For such high weight (7 Ton) structure it is convenient to have full welded joints. If this profile is not available in market, can manufacture it from plate guarder with edge preparation and full butt weld. For joining frame on Tundish Transfer Car bolted joints are useful because it is convenient for maintenance of car and other equipment. With the help of hex bolt and nut with high tensile property.

H. Problem Statement

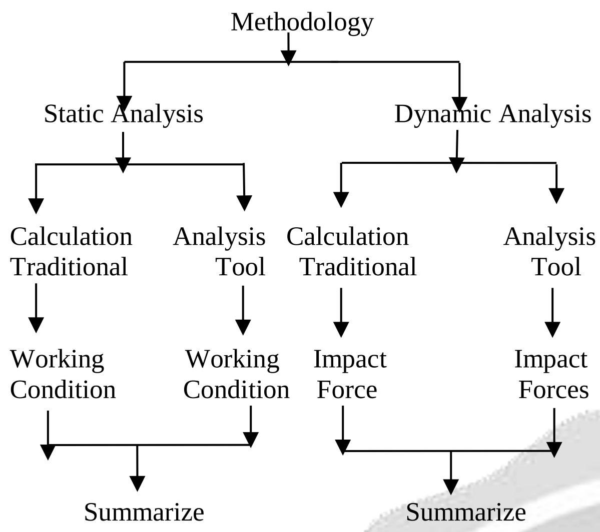
In one of case Tundish may carries full of semi solid metals in it while returning back to maintenance area. In such high temperature liquid handling activity, failure to handling will create hazardous situation to the surrounding set up and being. To keep the safety point of view, need of to design the vehicle with consideration of all its expected working condition is necessary. If found in previous studies that most of the failures are occur in variation in loading and unloading of Tundish. If the control of Tundish car fails, miss behavior of car will create dead stop impact. Here such expected condition are considered to design Tundish transport car and its subunits.

I. Objectives

- To study of force distribution on the resting pallet
- To find deflection and stress value by calculation and analysis in static working condition.
- To find deflection and stress value of loading and unloading condition
- To find optimized beam size and physical parameters
- To compare results of calculation, analysis and expected condition

J. Methodology

- Data collection through all expected condition,
- Calculation design for normal working condition,
- Calculation design for expected working condition,
- FEA Analysis for both of above working cases
- Comparing results in static and dynamic condition
- Comparing The Result With Calculation And Analysis
- Finalized the output model for manufacturing



II. DESIGN PARAMETER

A. Properties of Construction Materials

Standard [9] [10]: EN 10025-2:2004, European standard for hot-rolled structural steel. Part 2 - Technical delivery conditions for non-alloy structural steels. Steel Grade: S235JR; Number: 1.0038;
Weld ability: This steel grade is generally suitable to welding.
The tables below show the mechanical properties of grade S235JR:

TABLE3
MATERIAL PROPERTY

Steel Grade	Minimum yield strength Reh MPa	Tensile strength Rm MPa	Minimum elongation - A Lo = 5,65 * √So (%)	Notch Impact test
S235JR	200-235	360-510	22-26	27

Steel Grade	Youngs Module GPa	Poisson's Ratio (-)	Shear Module GPa	Specific heat capacity 50/100°C (J/kg°K)
S235JR	210	0.3	80	460-480

Boundary Condition/ Allowable Properties-

TABLE4
BOUNDARY CONDITION

Steel Grade	Allowable Stress N/mm2	Allowable Deflection mm
S235JR	120	L/1000

III. STATIC DESIGN

To start with static design, consider following three working condition

1) Empty Tundish car or without Tundish
2) Tundish car with empty Tundish
3) Tundish car with full Tundish

Following image shows the introduction of pallet member sizes and position with line diagram,

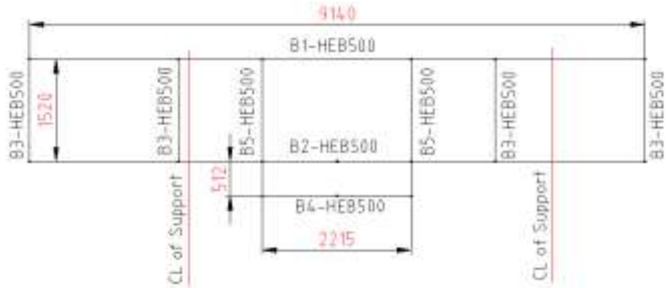


Fig 5: Line Diagram

In above figure B1, B2 and B4 are the load carrying member and B3 member are resting member. At primary concept we consider as resting member as HEB 300 and load carrying member as HEB 500.
Following are the properties on members, where I is the moment of inertia, S is the border distance and A is the area of respective member

TABLE5
PROPERTIES OF STRUCTURAL MEMBER

Properties	**Resting Member HEB 300**	**Load Carrying HEB 500**
I1 (mm^4)	251656000	1071757000
I2 (mm^4)	856283000	126239200
Sc (mm)	150	250
St (mm)	150	250
A (mm^2)	14907	23864

Total weight of full Tundish is 90,000 kg (approx.90 TON)
Total weight of Tundish pallet is 7000 kg (approx.7 TON)
Dead weight on Tundish car –
(90+7) x 1.5 = 145.5 Ton (approx. 1455000 N)
By considering 3 point resting condition above load with distribute on any the 3 contact surface and remaining surface will be remain redundant. By symmetric distribution of load every contact point may carry 48.5 ton load.

A. **Resting Member Load Test**

By applying UDL of 800 N/mm (48.5Ton/600mm), on HEB 300 on 1500 span. In which resting contact surface will be 600 mm and connecting point are full welded.
Following results occur

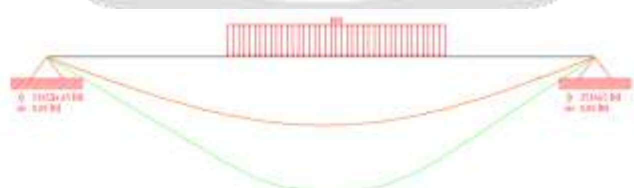


Fig 6: Output Plotted from Autodesk Deflection and Moment calculation Module

In which first connecting point is having reaction of 226534 N and second connecting point is having reaction of 253465 N.

TABLE 6
RESULT OF DEFLECTION AND MOMENT CALCULATION MODULE

Resting Member Deflection and Moment Calculation			
Moment of Inertia	I1	[mm^4]	251656000
Moment of Inertia	I2	[mm^4]	85628300
Moment of Inertia	Ieff	[mm^4]	251656000
Max. Border Dist.		[mm]	150
Safety Factor			2.7127
Yield Point		[N/mm^2]	235
E-Modulus		[N/mm^2]	210000
Material			S235JR
Max.Deflection	S1	[mm]	0.092825 E-15
Max.Bending Moment	Mb1	[Nm]	6.9356 E-12
Max.Deflection	S2	[mm]	0.609097
Max.Bending Moment	Mb2	[Nm]	145.34 E3
Max.Stress	Res.	[N/mm^2]	86.630
Max.Deflection	Sres	[mm]	0.609097
Max.Bending Moment	Mbres	[Nm]	145.34 E3
Scale for Defl. Line			310.9000:1
Scale for Bending Mom. Line			1:383.7400

B. **Load Carrying Member Test**

By putting maximum reaction 253464 N load carrying member with respective loading point. In this case pallet will rest and bolt on Tundish car and act like fixed support. With 5 point load on B2 member and bolting support from bottom side shows following results

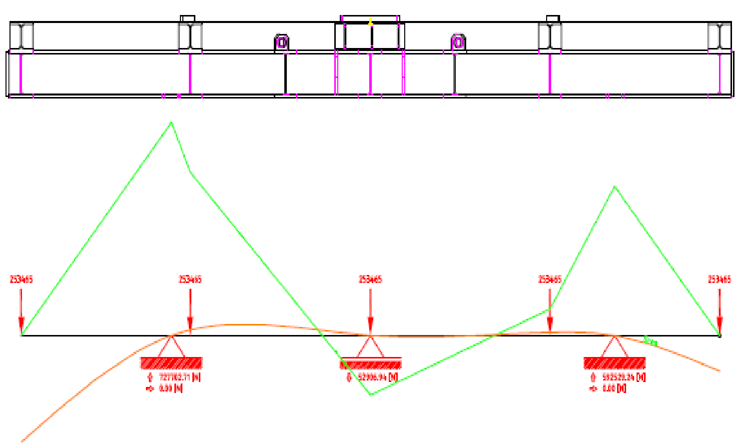


Fig 7: Output Plotted from Autodesk Deflection and Moment calculation Module

And the output result as below,

TABLE 7
RESULT OF DEFLECTION AND MOMENT CALCULATION MODULE

Load Carrying Member B2 Deflection and Moment Calculation			
Moment of Inertia	I1	[mm^4]	1071757000
Moment of Inertia	I2	[mm^4]	126239200
Moment of Inertia	Ieff	[mm^4]	1071757000
Max. Border Dist.		[mm]	250
Safety Factor			2.0228
Yield Point		[N/mm^2]	235
E-Modulus		[N/mm^2]	210000
Material			S235JR
Max.Deflection	S1	[mm]	0.000000
Max.Bending Moment	Mb1	[Nm]	0.0000
Max.Deflection	S2	[mm]	5.690117
Max.Bending Moment	Mb2	[Nm]	498.05 E3
Max.Stress	Res.	[N/mm^2]	116.17
Max.Deflection	Sres	[mm]	5.690117
Max.Bending Moment	Mbres	[Nm]	498.05 E3
Scale for Defl. Line			200.7900:1
Scale for Bending Mom. Line			1:217.9700

IV. ANALYSIS FOR STATIC CONDITION

Same model of Tundish pallet studied for stress analysis through below Von Mises Stress. Following are the details of set up,

A. General objective and settings:

TABLE 8
BASIC SETUP AND PARAMETERS

Analyzed File:	10000734462_IPT_000.ipt
Autodesk Inventor Version:	2015 SP2 (Build 190223200, 223)
Creation Date:	02/01/18, 7:38 PM
Simulation Author:	HOBH
Temperature:	100°C
Material	1.0038 / S235JR+AR
Density	7.85 g/cm^3
Mass	7030.43 kg
Area	78852800 mm^2
Volume	895597000 mm^3
Center of Gravity	x=142.721 mm y=69.6689 mm z=-0.656171 mm
Design Objective	Single Point
Simulation Type	Static Analysis
Detect and Eliminate Rigid Body Modes	No

Pallet is bond with Tundish car in bolted joints, and the face to face contact with each other. So here all constraint are fixed type.

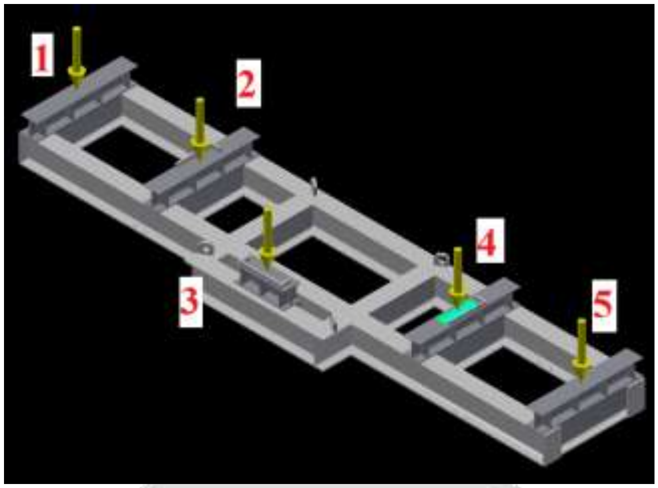


Fig 8: Load Allocation

Following are the results and output reaction

TABLE 8
RESULTANT REACTION

Name	Minimum	Maximum
Volume	895597000 mm^3	
Mass	7030.43 kg	
Von Mises Stress	0.0250012 MPa	110 MPa
1st Principal Stress	-117 MPa	33 MPa
3rd Principal Stress	-1371.55 MPa	164.188 MPa
Displacement	0 mm	6.36989 mm
Safety Factor	1.44358 ul	5 ul

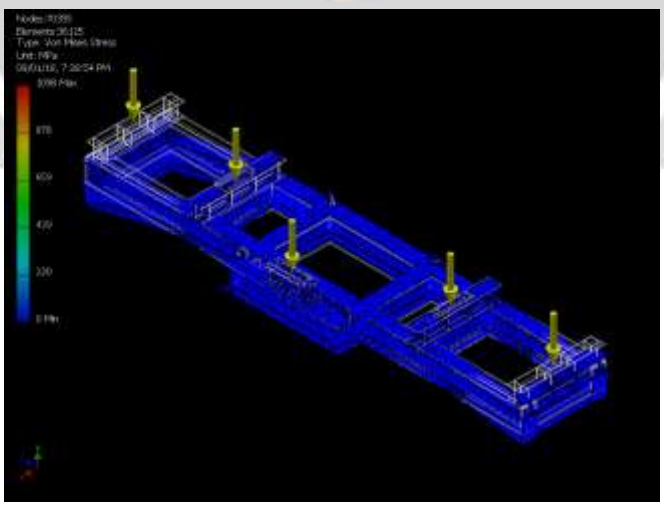


Fig 9: Von Mises Stress

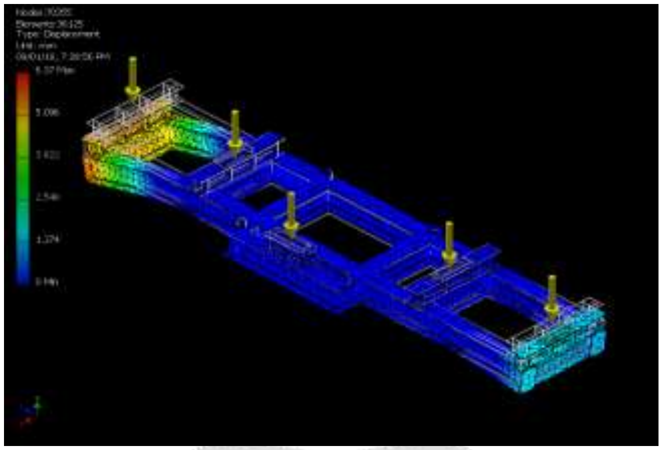


Fig 10: Displacement

V. COMPARISON OF RESULT

Following are the factor to be compare in calculus and analysis method with static load condition. They are nearly matching with each other. Below is the result of static analysis design.

TABLE 9
COMPARE CHART

Name	Calculation Method	Analysis Method
Max Stress	116.17 MPa	110 MPa
Displacement	5.69 mm	6.36989 mm
Safety Factor	2.02	Min 1.4

VI. DYNAMIC DESIGN

For dynamic analysis, the loading of tundish on tundish car is considered. While loading tundish with full of molten mtetal condition by using crane, one impact is must be occur. This impact is with respect to crane operator skill. Skillful crane operator will operate with smooth seating and non-skill employee may place with more impact. This impact can be calculated in following two manner…

- Dynamic calculation
- Dynamic analysis

A. **Dynamic calculation [2]**

To study the dynamic behavior we need to calculate, tundish force on pallet body expect to act.
Total weight of full tundish- 145500Kg (145.5 T)
Impact Force = 2xMass x Velocity x Time
F = 2mvt
m= mass of tundish; 145500 Kg
Here initial velocity consider as 4 m/s
Final velocity at impact considered as 0 m/s
The object will fall form 100 mm, it will 2 second to travel
F=2x90000x4x2
F=1080000 N

Impact force (1080000 N) is 1.2 times of dead load (900000) of tundish. This force transfer to three legs only out of five, with respect to three point 3-2-1 principle. So the force is divided in three resting point. By considering impact force factor 1.2 time of dead weight.

Impact for per leg is (480000x1.2) 576000 N. by applying this force to load carrying member (HEB 500) following share force curve and bending moment diagram found.

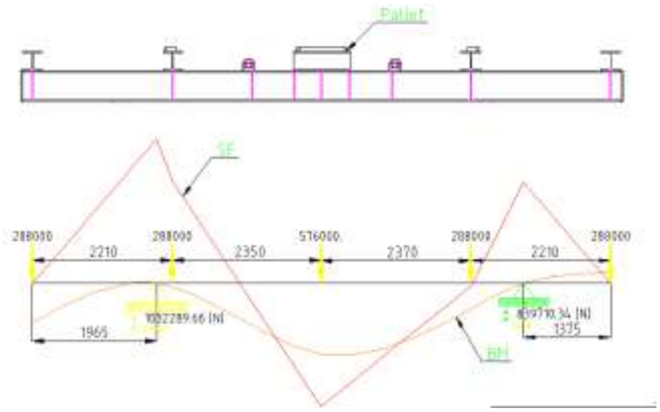


Fig 11: Output Plotted from Autodesk Deflection and Moment calculation Module

As shown in above figure the reaction at both resting point are 1082289 N and 839710 N and as given in below Table 10 maximum deflection is 4.4 mm and maximum stress is 143 N/mm². The deflection and stress level is above expectation level, so the pallet need to modify.

TABLE 10
RESULT OF DEFLECTION AND MOMENT CALCULATION MODULE

Moment of Inertia	I1	[mm^4]	1071757000
Moment of Inertia	I2	[mm^4]	126239200
Moment of Inertia	Ieff	[mm^4]	1071757000
Max. Border Dist.		[mm]	250
Safety Factor			1.6433
Yield Point		[N/mm^2]	235
E-Modulus		[N/mm^2]	210000
Material			S235JR
Max.Deflection	S1	[mm]	0
Max.Bending Moment	Mb1	[Nm]	0
Max.Deflection	S2	[mm]	4.433535
Max.Bending Moment	Mb2	[Nm]	613.08 E3
Max.Stress	Res.	[N/mm^2]	143.00
Max.Deflection	Sres	[mm]	4.433535
Max.Bending Moment	Mbres	[Nm]	613.08 E3
Scale for Defl. Line			257.7:1
Scale for Bending Mom. Line			1:268.3

VII. RESULTS

1) Initial model is not suit to expected boundary condition in which the max. Stress level (116 Mpa) and deflection (6.3 mm) need to improve for that reason model is revised.

2) While loading Tundish on Tundish car pallet by crane, the impact force happened is 1.2 times of static force of the whole equipment.

3) To verify the dynamic force 2D analysis, it need to do analysis have 3D analysis with respective condition.

VIII. CONCLUSION

In the conclusion the model calculated at 100°C in static and dynamic condition with calculus and 3D analysis method. This two result compare and found the higher stress level and higher deflection level. So the model is modified and recalculated for dynamic condition for the calculus and analytical method. The impact loading factor found 1.2 times then the static parameters. This model is again need optimized and analyze same for final manufacturing.

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