Tire - Rim Interactions for Ultra Class Trucks in The Mining Industry

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ABSTRACT: With the advent of ultra class trucks in the 320 ton + category, tire manufacturers have produced ultra class tires to match and provide greater floatation capacity for these units when riding over soft ground In all types of ground environment, trucks are developing high g loading conditions which produce adverse reactions at the tire - rim interface, causing damage not only to tires, but more surprisingly to rims In an effort to develop an understanding of this phenomenon, a tire - rim model is being developed to assist rim manufacturers m providing designs that will resist damage and protect the tire The effect on both components due to variable loading conditions is examined, where rim component geometry and tire performance are essential contributions

1 INTRODUCTION

The need for increased production has driven global surface mining operations to move to larger equipment As a result of this, trucks have moved into the ultra-class category while rim development has remained relatively stagnant More than ever there is the need for increased development and research of rims as many haulers currently operating are exposed to unanticipated high g loading, especially those operating with soft underfoot conditions, one of the primary causes of high g loading As a result, rims are cracking and failing at an unprecedented rate The majority of design modifications of the current generation of rims are scale increases of older designs and field fits This lack of engineered design or understanding of the consequences of high g loading, has resulted in several instances of rim failure leading to lost production, injuries, and even fatalities (North Queensland Tyre Fitters Workshop Meeting 2004 and Occupational Safety and Health Service, Department of Labour, New Zealand 2004) With an improved understanding of the performance of rims and tires subjected to high g loading, the knowledge base in this field will be expanded to allow manufacturers to target improved designs that will minimize rim cracks and failures that plague today's mining industry

2 PREVIOUS WORK

There has been very little published m regards to ultra class hauler rims, especially in terms of the effects of high impact loading The Society of Automotive Engineers (SAE) have published a handful of practices and standards for construction vehicle rims (SAE J751 1997, SAE J1315 1991, and SAE J1337 1997) but in terms of ultra class rims, their only practical use is that of component identification, Figure 1

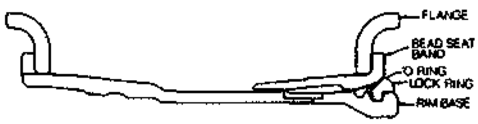

Figure 1 Cross-section view of standard 5-piece rim (SAE J751, 1997)

There has been some work done in regards to determining pressures exerted at the ground level which is useful for examining the interaction between a nm and tire (Wiermann et al 1999, Ronaı & Shmulevıch 1995, Tielkmg 1994, Tıelkıng & Abraham 1990, and Cunagm and Grubbs 1984) Unfortunately the bulk of this work has been done by both agricultural and transportation industries m order to determine information on large farm and highway vehicles, both of which are too small of scale for comparison to ultra class haulers. This lack of published work in regards to both high g loading on rims and large scale tire data acquisition, along with the high frequency of incidents regarding tire and rim failures speak volumes about the need for such information for today's mining industry.

In contrast to the lack of information regarding high impact loading on large scale rims and tires, there has been considerable work done on high g loading on other components of large scale mining equipment (Joseph 2003, Joseph 2002, and Joseph & Hansen 2002). These papers discuss in depth the effects of high g loading on mobile mining equipment and how it is detrimental to equipment life. They also discuss how soft underfoot conditions result in high g loading, such as those in the oil sand of Northern Alberta, which is where a vast number of large scale rims and tires are in use.

3 OBJECTIVES

The primary purpose of this research is to improve safety conditions at mine sites, as well as to minimize repair and replacement costs of rims and tires for large scale equipment. These objectives will be achieved by increasing the understanding of the interaction between the rim, the tire, and the ground. This includes gaining an improved appreciation of the stress-strain concentrations of the rim and tire, as well as acquiring more information regarding the transfer of forces between rim, tire and ground. This research will target to determine if high g loading is being experienced, and if it is indeed significant and detrimental at the rim/tire locale, as reported instances of as high as 4g have been measured at the strut level for ultra class heavy haulers in operation today.

It is proposed that a design modification will be suggested for rims that are currently in use with ultra-class heavy haulers. A goal of lower frequency of rim cracks and failures, leading to safer working conditions around rims, as well as decreased reactive maintenance and replacement for ultra-class rims and tires is targeted.

4 LARGE SCALE TESTING

In order to gain an improved understanding of the performance of and interaction between rims and tires, a series of loading tests that will simulate the forces that ultra-class haul trucks are subjected to on a daily basis will be performed. The results obtained from these tests will then be compared to a finite element model for verification purposes. If it is found that there is a correlation between the physical and computational representation, it will then be possible to make modifications to the computer model in order to determine a rim design that can withstand the high g loading at current exposure levels.

Currently ultra class haulers use 55/80 R63 or 59/80 R63 tires, which have outer diameters of 154" and 159", loaded radii of 64" and 69", and rim diameters of 63" respectively (Bridgestone 2001 and Michelin Earthmover 2005). Therefore, in order to perform an accurate loading test as described previously, a 55/80 R63 or 59/80 R63 tire and matching size rim should be used. However, the University of Alberta is unable to accommodate testing at this scale. The bulk of large scale testing facilities are located in the southern United States or overseas in Japan, and are therefore not feasibly accessible. Consequently, it was decided to test the largest possible rim and tire given the available resources at the University of Alberta, verify the results using a finite element model for the given tire and rim, then compare and correlate the results with a finite element model of either a 55/80 R63 or 59/80 R63 tire and a 63" rim. The tire and rim combination was selected was a 30.00 R51 tire, with an external diameter of 112" and a loaded radius of 50", donated by Kaltire, and a 51" diameter rim, figure 2, fabricated and donated by Rimex.

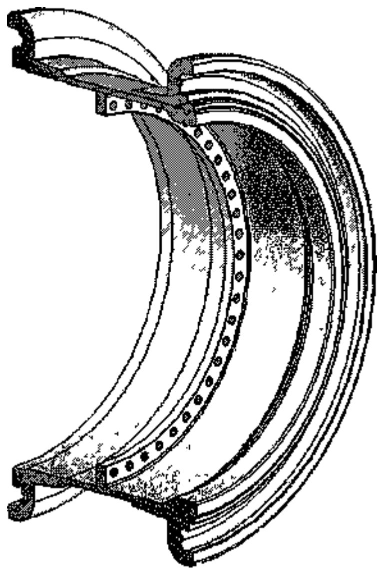

Figure 2 Cross-section view of 51" diameter rim

The. purpose of the load test on the 30.00 R51 tire and rim, figure 3, is to examine the impact of high g loading; upwards of 4g in worse case scenarios and frequently reaching 3g during day to day operations, which have been detected by ultra class hauler on-board monitoring systems operating in the oil sand. The tire and rim will initially be subjected to a lg loading (the static weight of a loaded haul truck), and the status of both components monitored via strain gauges. In order to simulate the effect of increased g levels resulting from dynamic loading, the loaded gross vehicle weight is multiplied by the proportion of g loading, applied statically to the rim and tire. The typical payload for a hauler that is used with this sized tire and rim is 170 tons, giving a total gross vehicle weight of approximately 550,000 lbs (Caterpillar 2004). This results in a loading of 92,000 lbs being experienced by each of the truck's 6 rims, based on a standard front-to-rear load distribution of 1/3 to 2/3. For the initial 1 g loading described above rim and tire will be loaded to 92,000 lbs, and then loaded by 0.1 g increments up to 2g, or 184,000 lbs. This range will allow a prediction of higher g loading effects based on the trending displayed, while eliminating the safety risk associated with testing the rim and tire at levels higher than 2g.

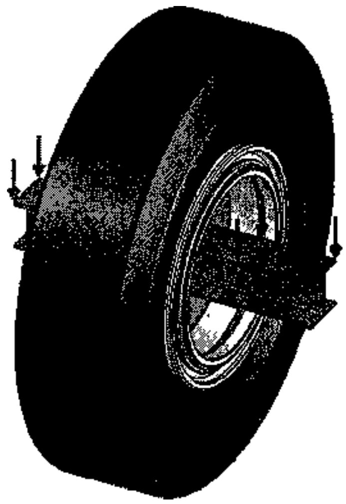

Figure 3 30.00 R51 tire and rim loading configuration

For each of the incremental g loading tests, the tire tread will be inked to show the surface contact area with increased loading. This will allow the measurement of the footprint of the tire for each level of loading, which also can be used to predict the area of contact at higher levels of g loading from the trends shown. This information will be vital in determining the value of the reaction forces that are transferred from the ground through the tire and onto the rim during motion of the hauler while subjected to various levels of g loading.

After the static loading tests have been completed, the rim and tire will be subjected to various cyclic loadings, which will be representative of various g levels (1.2g, 1.4g, 1.6g), for extended periods of time at varying frequency from 0.1 Hz to 3 Hz. This will provide valuable information in regards to continuous exposure high g impacts over time. The data collected from each of these tests should provide valuable insight into the impact of high g loading on the rim and tire assembly of an ultra-class haul truck and provide a basis of comparison for the computational analysis that will be performed.

5 COMPUTER MODELING

The computer modeling portion of the research project will be achieved using SolidWorks for 3D drafting and COSMOS for finite element analysis. Both software packages are off-the-shelf products for simplicity of application. Drawings were kindly provided by Rimex for the 51" diameter rim that will be subjected to the tests outlined above, as well as for 63" diameter rims that Rimex manufactures for Caterpillar Inc.'s 797B, figure 4, ultra class model and Komatsu Mining Systems 930E, figure 5, ultra class model.

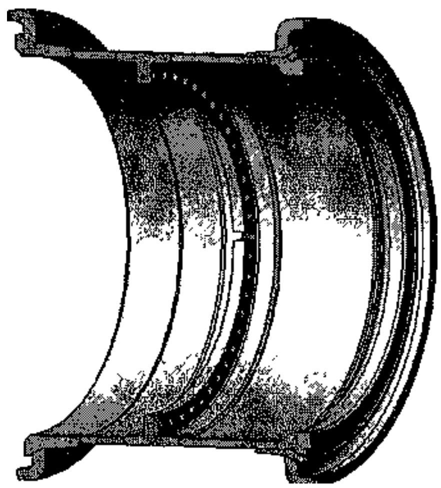

Figure 4 Cross-section view of Caterpillar 797B 63" diameter rim

According to the specifications, each of these rims are entirely constructed using ASTM A36 steel, making the input for the finite element modeling process simpler. However, modeling of the tire is very complex due to its dual material nature. The tires contain radial steel belting within their rubber body in order to provide structural support, which makes it hard to determine the overall material properties such as elastic modulus, shear modulus, and density. Tire manufacturers, for proprietary reasons, are very reluctant to provide information in regards to their tires. Therefore, it is planned to obtain samples of tread and sidewall materials for an ultra class earthmover tire, allowing material tests to be performed to obtain overall values for modulus and deformational response, which can then be input into the finite element model.

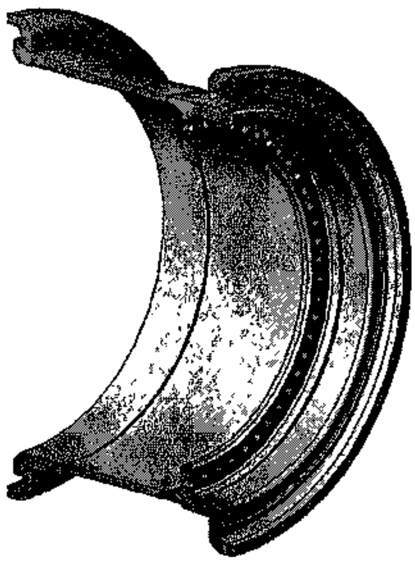

Figure 5 Cross-section view of Komatsu Mining Systems 930E 63" diameter nm

Once all the tire data has been obtained it will be possible to construct finite element models for the 30.00 R 51 tire and rim, as well as Caterpillar 797B and Komatsu 930E-2 loading variations for a 59/80 R63 tire and rim assembly. This will allow a comparison of the 30.00 R 51 tire and rim to the results obtained from the loading test for verification purposes. If it is found that there is a correlation between these results, then the similarities between the 51" and 63" rim models, such as strain locations and stress concentrations, can be inferred to the 59/80 R63 tire and rims that are subjected to similar loadings while operating. From there it will be possible to modify the current rim designs using SolidWorks and run several iterations of finite element analysis to determine the optimal rim design for high g loading.

6 PROJECT STATUS

The 30.00 R 51 tire that was donated by Kaltire and the 51" rim that was fabricated by Rimex arrived in Edmonton in early February 2005. They are currently assembled, the tire at partial inflation to maintain its shape, and are being stored until the loading test is ready to commence. The design of the mount that will hold the tire and nm in place during the test is being finalized and checked to ensure it has enough structural strength to withstand the loads that will be applied. As it stands, the plan is to pass a W 12X96 I-Beam through two plates, figure 6, that will be attached to each side of the mounting disc. Both sides of the I-Beam will be loaded with a total of half the required force at an equal distance from the centerline. Each of the plates will be split in two, as this will allow them to fit in the smaller opening on the outside edge of the rim, which has a smaller diameter than that of the plates. Splitting them in two will also ease in transportation, as each full plate will weigh over 800 lbs, without jeopardizing their structural strength, as they will both be bolted to the rim disc. Attached to these mounting plates will be four gussets that will provide structural support. They will be pre-welded into place at the locations shown in figure 7, but will still allow for the I Beam to be slotted between them.

Figure 6 Half-plate mounting disc with half I-beam slot

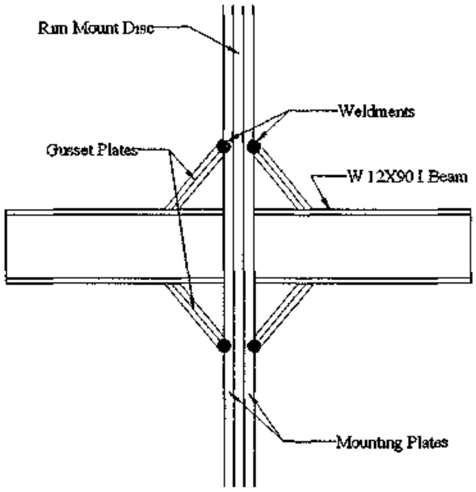

Figure 7 Gusset support plates

In terms of the computational modeling, the vast majority of the drafting is complete. As previously stated the mechanical properties for the rim components are easy to obtain as ASTM A36 is a very common material, however, until the properties of the tire tread and sidewalls are determined it is not possible to perform accurate analysis on the model. It is estimated that the loading test will be completed by late Spring 2005 while the computer modeling should be completed by Summer 2005, with analysis completed by Fall 2005.

7 ESTIMATED RESULTS

Without the proper material properties for the tire it is not possible to conduct an accurate finite element analysis. However, based on conversations with field personnel and other qualified people, an estimate of the magnitude of loading can be made on a 2-D basis, figure 8.

The peak value of the rim loading distribution can be estimated via the total vertical deformation of the tire, figure 9, during loading, given an approximation for the stiffness properties of the tire. It is known that the forces on the rim at the horizontal quadrants will be zero as the rim is loaded by the tire from the ground up; hence the top portion of the rim is not loaded during impact. Via these assumptions it is possible to draw a probable stress distribution on the rim, with the value of maximum load, and the slope of the function for maximum load both increasing as a function of g loading.

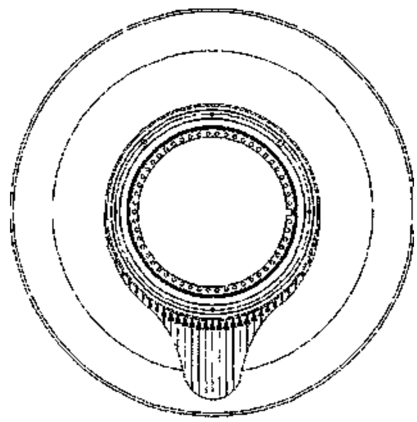

Figure 8 Estimated load distribution

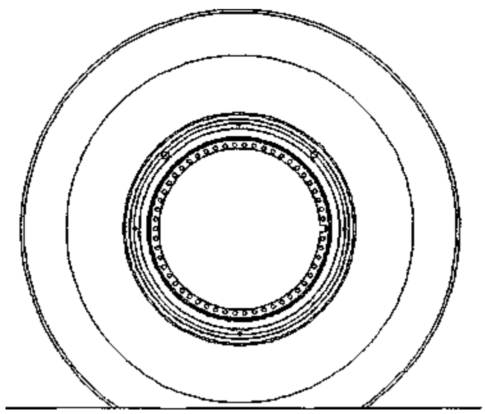

Figure 9 Deformation characteristics of tire

Modifications based on results from this research project would target a more even loading distribution with a less significant peak value, figure 10. This could be the result of a design change in terms of geometry of the rim components or in terms of material properties of the components, such as fabricating with a more flexible steel or weld material.

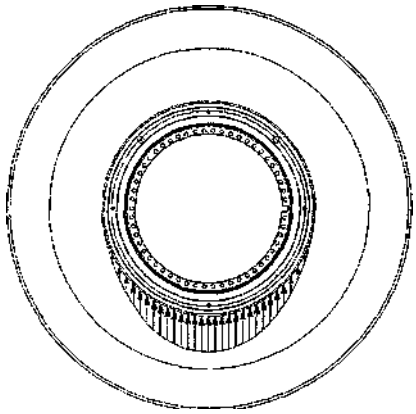

Figure 10 Idealized load distribution

8 DISCUSSION & CONCERNS

The primary concern in regards to this research project is whether a loaded 30.00 R51 tire and rim will provide accurate information in regards to what a larger, lower profile tire and rim will experience during operation. However, as stated previously the University of Alberta does not have the means to perform a large-scale loading test on either a 55/80 R63 or 59/80 R63 tire and rim.

It is expected that there will be a correlation between the information obtained from the finite element models for the 51" rim to the 63" rims, and it is expected that these tests and models will allow inference of performance characteristics to the larger scale, lower profile configuration now commonly in use with ultra class series units; 55/80 R63 and 59/80 R63.

Additional concerns in regards to this project are the weldments and weld materials used in constructing the rims. The center section of the rim is composed of several smaller components welded together, so the materials and therefore the material properties are not consistent throughout the entire piece. In the software, it is possible to create solid objects to represent the weld beads, whose properties can be altered to more accurately represent the weld material compared to the original A36 steel, rather than identifying the weld material and the base material as identical, which is impossible without perfect welding procedures and conditions. However, within the restrictions of the available software, it is not possible to appropriately model the weld induced heat-affected zone, which extends several centimeters from the weld locations, and is generally the location of cracks resulting from inadequate pre-heating or post-weld heat-treatment.

9 CONCLUSIONS

In order to gain an improved understanding of rim and tire performance when exposed to high g loading, a static and dynamic suite of loading tests are proposed that will simulate the forces that large tires and rims are exposed to during day to day mining operations. The tests will be performed on a 30.00 R51 tire and rim which have been donated by Kaltire and Rimex respectively. The values of loading will range from lg up to 2g in O.lg increments in order to develop a trend to enable prediction of load impacts upwards of 4g. The tread section of the tire will also be inked during these tests in order to obtain a stamp of the foot print during loading, as this will provide information in regards to the interaction between the ground material and the tire/rim assembly. In addition to these tests the rim and tire will be subjected to various loads within the lg - 2g range at a range of frequencies, providing information in regards to the effect of long term exposure to high g loading.

Once this data has been obtained it will be used to verify a finite element analysis of the 30.00 R51 tire and rim. The analysis of the 30.00 R51 tire/rim assembly will then be compared to that of a 59/80 R63 tire and rim, which will allow the determination and verification of stress and strain concentrations. The ultra class rim designs can then be modified, resulting in an optimal design for high g loading conditions.

This ensuing design should result in improved rim life cycles which will reduce mining operation's costs in terms of rim maintenance and replacement. More importantly, there should be significantly less rim failures and cracking, which will cause a decrease in the amount of hazardous work mine employees are exposed to in terms of rim maintenance.

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