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AUTOMOTIVE WHEEL HUB

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ABSTRACT

The wheel hub connects the wheel and brake disc to the suspension of a vehicle. It is mounted on the wheel bearing, carries the wheel studs on its flange and transmits the weight of the vehicle, the cornering forces and the braking torque from the wheel to the knuckle. Because the hub rotates with the wheel, it is subjected to a load that changes direction once in every revolution, and a crack in its flange or spindle can cause the wheel to separate from the vehicle. The hub is also part of the unsprung and rotating mass, so a lighter hub improves ride, handling, acceleration and braking response.

This paper presents the design and analysis of a front wheel hub for a compact passenger car with a gross mass of 1,250 kg. The hub, with a four-stud flange on a pitch circle diameter of 100 mm and an integral bearing seat, was modelled in CATIA and analysed in ANSYS Workbench. The governing load case combined a vertical bump load of 9.2 kN, a lateral cornering load of 4.4 kN and a braking torque of 1,150 N m. Static structural, modal, steady-state thermal with coupled thermal-structural, and fatigue analyses were carried out to evaluate strength, stiffness, vibration behaviour, the effect of brake heat and service life.

Four materials were compared on the same geometry, mesh and loads: grey cast iron, structural steel, aluminium alloy 6061-T6 and aluminium alloy 7075-T6. The maximum von Mises stress was between 98.6 and 101.3 MPa for all materials and appeared at the fillet between the flange and the hub barrel close to the stud holes. The factor of safety was 2.64 for grey cast iron on its ultimate strength, 2.47 for structural steel, 2.78 for aluminium 6061-T6 and 5.04 for aluminium 7075-T6. The hub mass was 2.86 kg in cast iron, 3.12 kg in steel, 1.07 kg in 6061-T6 and 1.12 kg in 7075-T6.

The thermal analysis, with the brake disc mounting face held at 180 degrees Celsius, gave a peak hub temperature of 142 degrees Celsius at the flange and 68 degrees Celsius at the bearing seat. When this temperature field was combined with the mechanical loads, the stress in the 7075-T6 hub rose to 128.5 MPa while its yield strength fell to about 440 MPa, giving a factor of safety of 3.42. The 6061-T6 hub dropped to a factor of 1.91 and did not reach the fatigue target of one million cycles. Forged aluminium 7075-T6 was therefore selected, giving a mass reduction of 60.8 percent compared with the cast iron hub and a first natural frequency of 1,634 Hz.

The study shows that a finite element based design workflow can compare materials, account for the heat flowing from the brake into the hub and identify critical regions such as the flange fillet and stud bosses before any casting or forging is made. The procedure reduces dependence on prototype testing, supports a well reasoned choice

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of material and gives a substantial reduction in rotating mass. It can be extended to rear hubs, hub-bearing units and wheel carriers in future work.

I. INTRODUCTION

Every wheel of a road vehicle is attached to the suspension through a hub. In a modern front-wheel-drive car the hub carries the wheel bearing, provides a flange to which the brake disc and the wheel are bolted through studs, and in driven wheels receives the drive shaft through a splined bore. The hub must locate the wheel accurately, support all the forces that act between the tyre and the road and transmit braking and driving torque. At the same time it rotates at wheel speed, so its mass contributes both to the unsprung mass and to the rotational inertia of the wheel assembly.

The loads acting on a hub are complex. The vertical load from the weight of the vehicle increases sharply when the wheel passes over a bump or a pothole. Lateral forces during cornering create a bending moment on the flange and the barrel because they act at the tyre radius. Braking produces a torque that is transferred from the disc through the studs and the flange. As the hub rotates, each point on it passes alternately through tension and compression, so even a steady load produces a fully reversed stress cycle. In addition, heat generated during braking flows from the disc into the flange and changes both the stress and the strength of the material.

Wheel hubs have traditionally been made from cast iron or forged carbon steel because these materials are inexpensive, easy to machine and tolerant of the heat from the brake. However, both are heavy, and the drive towards lower fuel consumption and better handling has led manufacturers to consider aluminium alloys for hubs and wheel carriers. Aluminium offers a large saving in mass, but its lower stiffness, its lower fatigue strength and the loss of strength at elevated temperature must be examined carefully before it can replace iron or steel in such a safety-critical part.

The present work develops a three-dimensional model of a front wheel hub, applies the combined vertical, lateral and braking loads, includes the effect of brake heat through a thermal analysis, and compares four candidate materials in ANSYS Workbench. The objectives are to determine the stress, deformation, factor of safety, natural frequency, temperature distribution and fatigue life for each material, to identify the critical regions of the hub and to select a material that gives the lowest mass while satisfying all strength, stiffness and life targets. The study is restricted to a single front hub with an integral bearing seat, and the bearing, studs and brake disc are represented through their supports, loads and temperatures rather than modelled in detail. This keeps the model simple enough for a fair comparison of materials at the concept stage.

II. LITERATURE SURVEY

Investigations into wheel hub failures have reported that cracks usually begin at the fillet between the flange and the hub barrel, around the stud holes and at the edges of the bearing seat. These locations experience the highest bending stress when lateral forces act at the tyre radius, and the stress there alternates in every revolution of the

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wheel. Field studies of hub failures in light commercial vehicles have linked many of them to rotary bending fatigue, sometimes made worse by overloading, incorrect stud tightening or corrosion at the flange face. Researchers have recommended generous fillet radii, adequate flange thickness near the studs and careful control of surface finish, and they have stressed that hubs must be designed for fatigue under rotating loads rather than for a single static load.

Finite element analysis has been widely used to study wheel hubs and hub-bearing units. Typical studies build the hub geometry in CATIA, SolidWorks or a similar package and analyse it in ANSYS with second-order tetrahedral elements, refining the mesh near the fillets and stud holes. The bearing seat is usually represented by a cylindrical or fixed support, while the wheel forces are applied through the stud holes or the flange face. These studies report good agreement between predicted critical regions and observed crack sites. They also show that the way loads are transferred into the flange has a strong effect on local stress, so loads applied at a single point give unrealistically high values and should be distributed over the contact areas.

Material comparison for hubs has received considerable attention. Reported studies have compared grey and ductile cast iron, carbon and alloy steels, aluminium alloys and, in some cases, magnesium alloys and metal matrix composites under the same geometry and loads. A common conclusion is that the stress distribution is almost independent of material, while deformation increases as the elastic modulus falls and mass falls in proportion to density. Grey cast iron is economical but brittle and weak in fatigue, steel is strong but heavy, and aluminium alloys offer large mass savings. Among aluminium alloys, the high-strength 7000 series has been found to provide adequate margins where the 6000 series approaches its fatigue limit.

The influence of brake heat on hub design has been examined in studies that couple thermal and structural analyses. Heat generated at the friction surfaces of the disc passes into the hub through the mounting face, and the flange can reach temperatures well above ambient during repeated or downhill braking. Researchers have shown that this temperature rise introduces thermal stress because of the temperature gradient between the flange and the bearing seat, and that it lowers the yield and fatigue strength of aluminium alloys more than that of steels. Coupled analyses in which the temperature field from a steady-state thermal solution is imported into the structural solution have been recommended for aluminium hubs, because the margin found at room temperature may otherwise be overestimated.

Weight reduction of hubs and other rotating suspension parts has also been studied through shape optimisation and through modal analysis. Studies have removed material from the flange between the studs, reduced barrel wall thickness and added ribs where stiffness is needed, reporting useful mass savings without loss of strength. Modal analysis is used to confirm that the natural frequencies of the hub lie far above the wheel rotation frequency, which is less than about 20 Hz at normal highway speeds, and above the main suspension and brake vibration modes. The present work combines these ideas by comparing materials under static, thermal and fatigue conditions, checking natural frequencies and selecting the lightest material that satisfies all criteria.

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III. SYSTEM ANALYSIS

The design problem is to obtain a front wheel hub that carries the vertical, lateral and braking loads of a compact passenger car with a gross mass of 1,250 kg without yielding or fracture, keeps the wheel stiffly located, tolerates the heat conducted from the brake disc and survives at least one million rotating load cycles, while having the lowest practical mass. The hub has a four-stud flange of 136 mm outer diameter on a pitch circle of 100 mm with M12 studs, a disc pilot of 56 mm and a bearing seat of 45 mm diameter. The governing case combines a vertical bump load of 9.2 kN, a lateral cornering load of 4.4 kN acting at the tyre radius and a braking torque of 1,150 N m. The outputs required are the von Mises stress, total deformation, factor of safety, natural frequency, temperature field, coupled thermal-structural stress, fatigue life and mass. The targets are a factor of safety of at least 2.5 including brake heat, a fatigue life of at least one million cycles and a first natural frequency far above wheel rotation frequency.

Existing System

In conventional practice a wheel hub is designed by scaling an earlier hub of a similar vehicle and checking a few sections by hand calculation, treating the flange as a plate and the barrel as a hollow shaft under bending. These calculations cannot represent the stress concentration at the flange fillet, the stud holes or the bearing seat shoulder, and they do not consider the temperature rise caused by braking. The usual response to this uncertainty is to use cast iron or steel with a thick flange and barrel, which gives a heavy hub. The design is then confirmed by casting or forging prototypes and testing them on rotary bending and cornering fatigue rigs, where each test can take many days. If a prototype cracks, the pattern or die is changed and new prototypes are produced. Evaluating a lighter material such as aluminium in this way involves new tooling, new test programmes and considerable cost, so material changes are seldom explored at the early design stage.

Disadvantages of Existing System

- Hand calculations simplify the flange and barrel into plates and shafts.
- Stress concentration at the flange fillet and stud holes is not predicted.
- The effect of brake heat on stress and material strength is ignored.
- Thick sections in cast iron or steel make the hub heavy.
- Each design change requires new patterns, dies and prototype parts.
- Rotary bending fatigue tests take many days for every variant.
- Lighter materials are rarely evaluated because of tooling and test cost.
- Natural frequencies of the hub are not checked during early design.
- Deformation at the bearing seat and flange face is not quantified.
- Regions where material could be removed safely are not identified.

Proposed System

The proposed approach uses computer-aided design and finite element analysis to evaluate the hub under mechanical and thermal loads before any prototype is made. The hub is modelled in CATIA with its flange, stud holes, disc pilot, barrel and

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bearing seat, and the geometry is transferred to ANSYS Workbench. Grey cast iron, structural steel, aluminium 6061-T6 and aluminium 7075-T6 are assigned in turn with the same mesh, supports and loads. A static structural analysis gives the stress, deformation and factor of safety under the combined bump, cornering and braking load. A modal analysis gives the natural frequencies. A steady-state thermal analysis with the disc mounting face at 180 degrees Celsius gives the temperature field, which is imported into a second structural analysis to obtain the coupled thermal-structural stress. Finally, the fatigue tool evaluates the life under fully reversed rotating loading. The material that satisfies every target with the lowest mass is selected for the final hub.

Advantages of Proposed System

- The complete hub geometry including flange, studs and bearing seat is analysed.
- Critical regions at the flange fillet and stud bosses are found before manufacture.
- Four materials are compared under identical geometry, mesh and loading.
- Combined bump, cornering and braking loads are applied in one governing case.
- Brake heat is included through a coupled thermal-structural analysis.
- Reduced material strength at elevated temperature is taken into account.
- Natural frequencies are confirmed to be far above wheel rotation frequency.
- Fatigue life under rotating loads is estimated for every candidate material.
- Hub mass is reduced by 60.8 percent compared with the cast iron design.
- Prototype testing is reserved for confirming the final selected design.

IV. METHODOLOGY

The methodology began with the calculation of wheel loads from the vehicle mass, weight distribution, bump factor, cornering acceleration and braking deceleration, giving the governing combined case. The hub was then modelled in CATIA and exported to ANSYS Workbench in STEP format. Material properties for the four candidates, including temperature-dependent yield strength and thermal conductivity, were assigned from the engineering data library. The hub was meshed with ten-node tetrahedral elements refined at the flange fillet and stud holes; a convergence study at 6, 5, 4, 3 and 2.5 mm element size showed a change of 1.3 percent in peak stress between the last two sizes, so a 3 mm mesh with 211,540 nodes and 139,862 elements was used. A cylindrical support was applied at the bearing seat, the vertical and lateral forces were applied through the stud holes and the braking torque as a moment on the flange face. The static, modal, thermal, coupled and fatigue solutions were then solved and post-processed for every material.

SYSTEM ARCHITECTURE

The analysis workflow is arranged around the ANSYS Workbench solution as a central hub with the other stages connected to it. Vehicle data and wheel loads feed the solver with the combined vertical, lateral and braking case. The CATIA model supplies the hub geometry, and the engineering data library supplies the mechanical,

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thermal and temperature-dependent properties of the four materials. The meshing module supplies the refined tetrahedral mesh after the convergence check, and the boundary condition set supplies the bearing seat support, stud loads and braking moment. Around the central solution, four analysis branches are run: static structural for stress, deformation and safety factor, modal for natural frequencies, steady-state thermal with the coupled thermal-structural step for brake heat, and fatigue for life under rotating load. The results from all branches are collected in a material comparison, the design check tests them against the targets, and the selected material and final hub design are reported.

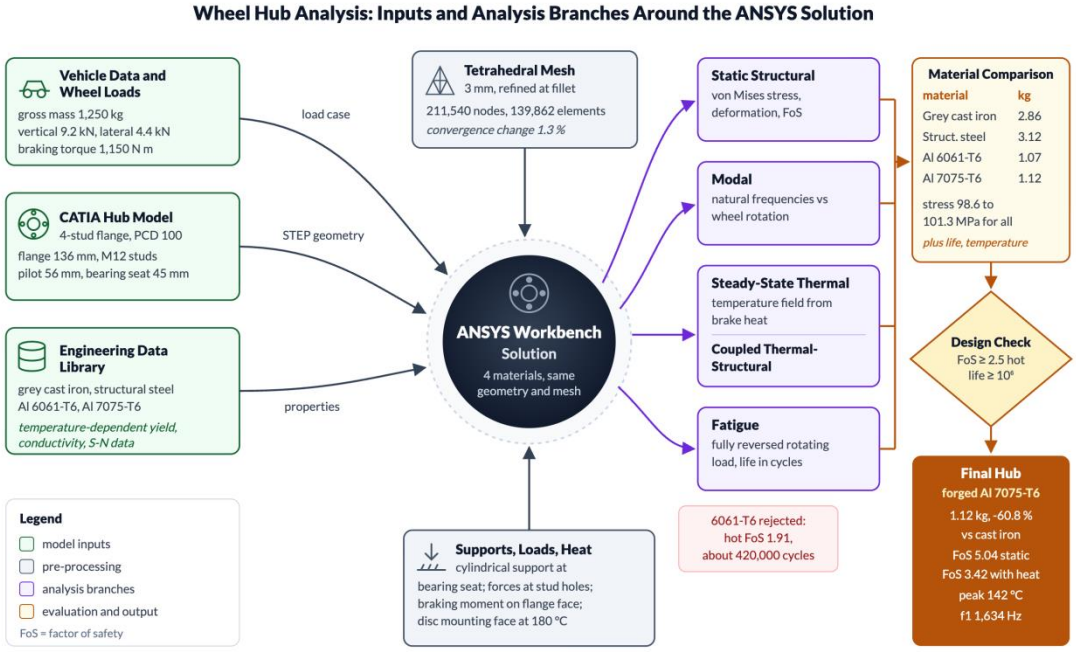


Fig. 1 System Architecture

V. RESULT AND OUTPUT

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Fig. 2 Result and Output Screen

VI. CONCLUSION

A front wheel hub for a compact passenger car was modelled in CATIA and analysed in ANSYS Workbench under a combined vertical bump load of 9.2 kN, lateral cornering load of 4.4 kN and braking torque of 1,150 N m. The maximum stress in every material occurred at the fillet between the flange and the hub barrel near the stud holes, which agrees with the crack locations reported for hubs in service. The convergence study confirmed that the predicted peak stresses were stable with respect to mesh size.

The four materials gave almost the same peak stress, between 98.6 and 101.3 MPa, but differed widely in mass, deformation and margin. Grey cast iron and structural steel gave adequate static margins but weighed 2.86 kg and 3.12 kg, and cast iron is also weak in fatigue. Aluminium 6061-T6 reduced the mass to 1.07 kg but its factor of safety fell to 1.91 once brake heat was included and its fatigue life was only about 420,000 cycles, short of the target. Aluminium 7075-T6 gave a static factor of safety of 5.04 and a coupled factor of 3.42 at 1.12 kg, with a fatigue life above one million cycles.

Forged aluminium 7075-T6 was therefore selected for the hub. It reduces the hub mass by 60.8 percent compared with cast iron and by 64.1 percent compared with steel, with a maximum total deformation of 0.109 mm under static load. Its first natural frequency of 1,634 Hz is far above the wheel rotation frequency of about 18 Hz at 120 km/h, and the peak temperature of 142 degrees Celsius at the flange remains within the range where the alloy retains adequate strength. The reduction in unsprung and rotating mass is expected to improve ride, handling and braking response. The lighter hub also lowers the rotational inertia of each front wheel

assembly, so less energy is spent in accelerating and braking the wheels during city driving.

Future work can include transient thermal analysis over repeated braking cycles, modelling of the wheel bearing with contact rather than a fixed support, the effect of stud preload on flange stress, and shape optimisation of the flange between the studs. Physical testing of a forged prototype on rotary bending and cornering fatigue rigs would confirm the predicted margins, and a cost comparison would show whether the weight saving justifies the higher price of forged aluminium for a given vehicle class. Corrosion protection of the aluminium flange where it contacts the steel brake disc and studs should also be examined, since galvanic corrosion at this joint can reduce fatigue life in wet road conditions.

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