Stress Analysis of Polycarbonate Spur Gears for Sugarcane Juice Machine Using FEA

Mr. Samadhan M. Lande
Department of Mechanical Engineering
Shree Ramachandran College of Engineering Lonikand
Pune, India
Email:samadhanlande1@rediffmail.com

Prof. Dr.A.D.Desai
Department of Mechanical Engineering
Shree Ramachandran College of Engineering Lonikand
Pune, India

Prof. A.B.Verma
Department of Mechanical Engineering
Shree Ramachandran College of Engineering Lonikand
Pune, India

Prof. A.V.Gaur
Department of Mechanical Engineering
BMIT Solapur

Abstract- This dissertation work describes design and analysis of Spur gear. In this work, it is advise to replace the metallic gear of sugarcane juice machine with plastic gears to reduce the weight as well as noise. Polyamide 66 and Teflon as plastic materials have been widely used at the manufacturing of gear mechanism .For the purpose Nylon and Polycarbonate plastic materials were considered namely and their feasibility are checked with respect to metallic gear (Cast iron). From the static analysis, the best plastic material is recommended for the purpose. Static analysis of a Gear tooth model has been performed using ANSYS® 10.0. The Finite Element Method is used for Plane stress analysis of a Spur Gear tooth model. Solution obtained by this method is approximately correct. Analytical methods that are used for getting correct solution of analysis problems. In this work by taking geometrical approximation of a model the plane stress analysis is made to increase the accuracy of a solution and to minimize the solution time. The loading conditions are assumed to be static. The element chosen is solid 8 node 183 (planer element). The bending stress and strain is calculated by this numerical method and compared with the solution obtained by analytical method. plastic gears are suitable for the application of sugarcane juice machine under only limited load conditions as compared to Cast Iron spur gears.

Keywords: *Cast Iron spur gears, Static analysis, Nylon spur gears, Polycarbonate spur gears, Plane stress analysis, FEM and ANSYS.*

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I. INTRODUCTION

A Gear can be defined as the mechanical element used for transmitting power and rotary motion from one shaft to another by means of progressive engagement of projections called teeth. Spur Gears use no intermediate link or connector and transmit the motion by direct contact. The two bodies have either a rolling or a sliding motion along the tangent at the point of contact. No motion is possible along the common normal as that will either break the contact or one body will tend to penetrate into the other. Thus, the load application is gradual which results in low impact stresses and reduction in noise. Therefore, the spur gears are used in transmitting power with very less friction losses [7]

Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology. [6] A Sugarcane juice machine as usually used in extracting sugarcane juice which consists of a set of gears, shafts. Their job is to convert the input provided by a prime mover (usually an electric motor) into an output with lower speed and correspondingly higher torque. In this dissertation, analysis of spur gear in a Sugarcane juice extractor machine was studied using FEM. [4]

1.1 Classification of Gears

a. Parallel Gears
- Spur Gear
- Helical Gear
- Rack and Pinion

b. Intersecting Gears
- Bevel Gear

c. Non-intersecting and Non parallel Gears
- Worm Gear

The use of machined plastic gears is increasing in industrial power transmission applications, Cast or extruded gear materials of 50 mm to over 2 meter (2"-84") in diameter are machined to desired dimensions and gear tooth forms. Nylons and acetals are the most widely used thermoplastic gear materials. They offer resiliency, resistance to wear and corrosion, noise reduction, vibration suppression, lightweight and minimum maintenance.

Plastics as gear materials represent an interesting development for gearing because they offer high strength-to-weight ratios ease of manufacture and excellent tribological properties. In particular, there is a sound prospect that plastic gears can be applied for power transmission of up to 10 kW. Typical plastic, such polyamide 66, more commonly known as nylon 66. Have long been known as suitable materials for gearing, it was reported that polyamide gear experienced fatigue failure before significant wear was observed, but crack initiation and propagation mechanisms were unclear. The failure mechanism of polyamide 66 (PA66) gears when run in like pairs are still not clear and, as a result, PA66 users have to substantially underrate their designs for gears. [14]

Plastic gears are serious alternative to traditional metal gears in a wide variety of applications, The use of plastic gears has expanded from low-power; precision motion trans-mission into more demanding power trans-mission applications. As designers push the limits of acceptable plastic gear applications, more is learned about the behavior of plastics in gearing and how to take advantage of their unique characteristics. Plastic gears provide a number of advantages over metal gears. They have less weight, lower inertia and are quieter than metal. Plastic gears often require no lubrication or can be compounded with internal lubricants such as PIFE or silicone. Plastic gears usually have a lower unit cost than metal gears and can be designed with part consolidation in mind to incorporate other feature needed in an assembly. These gears are also resistant to many corrosive environments.

The use of thermoplastic materials for gears hampered by a lack of established load carrying and wears performance data, at least when compared to that available for metal gears; nonetheless, there are certain guideline available for estimating the technical feasibility of their use. However, these guidelines have evolved from equations originally worked out for metals and do not take into account some of the unique behavior found in thermoplastic materials. [16]

Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The plastic materials have corrosion resistance, low electrical and thermal conductivity, easily formed into complex shapes, wide choices of appearance, colors and transparencies. The introduction of plastic materials was made it possible to reduce the weight of the spur gear without any reduction on load carrying capacity and stiffness [4].

The Nylon materials have high strength, good mechanical and abrasion resistance property, excellent wear resistance, resistant to most chemicals and self- lubricant. Polycarbonate materials have, high impact strength, good dimension stability and heat resistance. Since, Nylon and Poly carbonate have good properties as stated above the cast iron spur gears of sugarcane juice machine are being replaced by plastic spur gears. The plastic material offer opportunities for substantial weight saving but not always are cost-effective over their cast iron counter parts [4].

1.2 Definition of the Problem

In this dissertation work it is advise to replace the metallic gear of sugarcane juice machine with plastic gears to reduce the weight as well as noise. For this analysis two types of plastic materials were considered namely Nylon and Polycarbonate and their Feasibility checked with respect to metallic gear (Cast iron). From the static analysis, the best plastic material will be recommended for the purpose. After analysis a comparison is done with existing Cast iron spur gear. from the result of analysis we can choose the best one between the Nylon and Polycarbonate spur gears .

II. LITERATURE SURVEY

The review mainly focuses on replacement of Cast iron spur gears with the plastic spur gear in the application of sugarcane juice machine.

Mahebub Vohra, et.al. This paper gives information about design-optimization methodology to determine the comparative analysis of spur gear with different material for increase the possibility for application of polymer gears. Research and development on different material spur gear shows that if polymer are design-optimized with sufficient care, it can replace most of metallic gears to take additional benefits like low cost, easy manufacturing, low noise-vibration, low maintenance-lubrication.[1]

T. Shoba Rani, et.al. This paper gives information about efficiency, as deflections are less the efficiency of nylon spur gear is more than the cast iron spur gear, results in less noise and long life, The metallic gear results is more deflection compared to nylon and polycarbonate, the cost price and life of nylon is also good. When we replace the metallic spur gear with nylon gear there would be better results we can find in the automobile, robotic and in medical fields where the need of nylon gear is there. [2]

R. Yakut, et.al. In this study, load carrying capacity and occurring damages of gears which are made of PC/ABS blends were investigated. PC is hard material and ABS is soft material. The usage of materials limits these drawbacks. However PC and ABS polymers combine each other, the PC/ABS blends have suitable mechanical properties for gear applications in the industrial areas. In this study, usability of PC/ABS composite plastic materials as spur gear was investigated. PC/ABS gears were tested by applying three different loading at two different numbers of revolutions on the FZG experiment set. [3]

Mahesh Badithe, et.al. The main aim of this paper is to relieve stress from the maximum value to as minimum as possible. So the highest point of contact of teeth is selected as pressure application point which causes highest stress. Stress relieving feature having a shape of aero-fin is used in the path of stress flow which helped to regulate stress flow by redistributing the lines of force. This also yielded better results when compared to elliptical and circular holes. In this study, the best result is obtained by introducing aero-fin hole at (38.7653, 65.4083, 0) and having scaling factor of 0.6. The result displayed a stress reduction by 50.23% and displacement reduction by 45.34% [5]

2.1 Literature about dissertation topic

2.1.1 Sugarcane crusher Heavy duty machine - Technical Specifications

Cane Crushing capacity/hour 750 - 1000 Kg
Extraction 60 - 65 %
Power requirement 1.5 KW
Speed of Driving Pulley 1400 R.P.M
Size of Pulley 30" X 4. ½"
King Roller 8. 5/8" dia. X 8. ½"
Crushing Roller 6" dia. X 8. ½"
Extracting Roller 6. 1/8" dia. X 8. ½"
Net weight 615 Kg
Gross weight 750 Kg

-Geometric details of desired spur gear:

- Module (m) = 10 mm
- Addendum = 1 module
- Dedendum = 1.157module
- Pressure angle (α) = 20 degrees
- Tooth thickness (t) =1.571module
- Whole depth = 2.25 module

III. THEORETICAL ANALYSIS

3.1 Material Properties of Cast Iron, Nylon and Polycarbonate (10)

Table 1 Material Properties of Cast Iron, Nylon and polycarbonate

Material Property	Cast Iron	Nylon	Polycarbonate
Young's Modulus (N/mm^2)	1.65 x 10^5	2.1x 10^3	2.75 x 10^3
Poisson's Ratio	0.25	0.39	0.38
Density (Kg/mm^3)	7.2 x 10^{-6}	1.13 x 10^{-6}	1.1x 10^{-6}
Co-efficient of friction	1.1	0.15 - 0.25	0.31
Ultimate Tensile Strength (mpa)	320 – 350	55 - 83	55 – 70

Specifications of sugarcane juice machine motor

Power (P) = 1.5 kW = 1500watt
Speed (n) = 1400 RPM
Power (P) = 2π n t / 60
1500 = (2π x 1400 t) / 60
Torque (t) = (1500 x 60)/ (2π x 1400)
t = 10.2313 N-m
t = 102313 N-mm
t = P_t x (d/2)
P_t = t/ (d/2)
P_t = 10231/90
P_t = 113.677 N
Where 'P_t' is the Tangential load

Table2 Theoretical Results of Cast Iron Spur Gear

Sr. No	Load (P_t) N	Bending Stress (6b) N/mm^2	Strain
1	113.667	2.03	1.23 x 10^{-5}
2	227.334	4.07	2.46 x 10^{-5}
3	341.001	6.10	3.69 x 10^{-5}
4	454.668	8.14	4.93 x 10^{-5}
5	568.335	10.17	6.16 x 10^{-5}

Table3 Theoretical Results of Nylon Spur Gear

Sr. No	Load (P_t) N	Bending Stress (6b) N/mm^2	Strain
1	113.667	2.03	0.96 x 10^{-3}
2	227.334	4.07	1.93 x 10^{-3}
3	341.001	6.10	2.90 x 10^{-3}
4	454.668	8.14	3.87 x 10^{-3}
5	568.335	10.17	4.84 x 10^{-3}

Table4 Theoretical Results of Polycarbonate Spur Gear

Sr. No	Load (P_t) N	Bending Stress (6b) N/mm^2	Strain
1	113.667	2.03	0.73 x 10^{-3}
2	227.334	4.07	1.48 x 10^{-3}
3	341.001	6.10	2.21 x 10^{-3}
4	454.668	8.14	2.96 x 10^{-3}
5	568.335	10.17	3.69 x 10^{-3}

IV. COMPUTATIONAL ANALYSIS

4.1 Finite Element Analysis

Present work uses ANSYS for FE analysis of a spur gear. ANSYS is widely used FE analysis software both in academics as well as in industry. Using ANSYS one can perform various tasks of FE analysis and there is huge element library available to meet the user requirements of various type of analysis. There are two different user interfaces available i.e. ANSYS classic and ANSYS workbench. Traditionally, ANSYS classic is choice of analysts but of late ANSYS workbench is becoming popular with analysts. Present work used ANSYS classic version 10.

4.2 Generating Involute profile of a spur gear tooth

Involute profile can be generated in CATIA V5 by Parametric modeling workbench, but in this work it is developed by traditional drafting method in the CATIA V5 R21. The step by step procedure with CATIA images are given below.

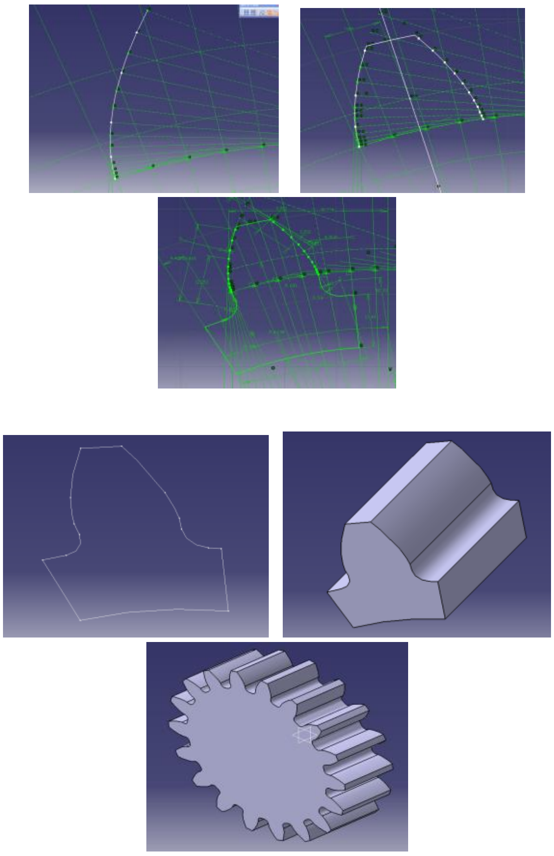


Figure1 Step by step procedure with CATIA images

4.3 Plane Stress Analysis

It is defined to be a state of stress in which the normal stress б$_z$, and the shear stresses б$_{xz}$ and б$_{yz}$ directed perpendicular to the x-y plane are assumed to be zero.

The geometry of the body is essentially that of a plate with one dimension much smaller than the others. The loads are applied uniformly over the thickness of the plate and act in the plane of the plate. The plane stress condition is the simplest form of behavior for continuum structures and represents situations frequently encountered in practice.

4.4 Finite Element Analysis
4.4.1 for Cast Iron Material

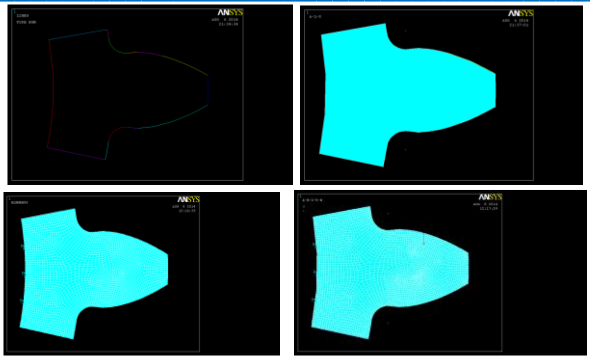


Figure2 FEA Preprocessor and Processor

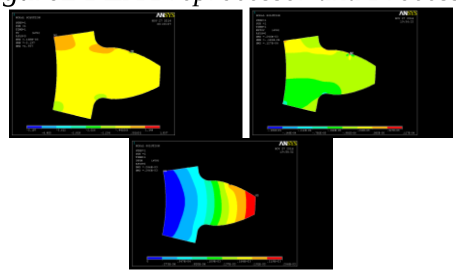


*Figure 3 bending stress, strain and displacement at **P_t=113.667 N***

Similarly bending stress, strain and displacement at ***P_t =227.334 N, 341.001N, 454.668N and at 568.335N** for Cast Iron, Nylon and Polycarbonate Material obtained Results in ANSYS are as shown below.*

Table5 Results of Cast Iron Spur Gear

Sr. No.	Force (N)	Stress	Strain	Displacement
2	227.334	3.874	2.54 x 10^{-5}	4.92 x 10^{-4}
3	341.001	5.811	3.80 x 10^{-5}	7.38 x 10^{-4}
4	454.668	7.748	5.07 x 10^{-5}	9.84 x 10^{-4}
5	568.335	9.685	6.34 x 10^{-5}	12.31 x 10^{-4}

Table6 Results of Nylon Spur Gear

Sr. No.	Force (N)	Stress	Strain	Displacement
1	113.667	1.937	1.08 x 10^{-3}	1.68 x 10^{-2}
2	227.334	3.874	2.17 x 10^{-3}	3.36 x 10^{-2}
3	341.001	5.811	3.25 x 10^{-3}	5.04 x 10^{-2}
4	454.668	7.748	4.33 x 10^{-3}	6.73 x 10^{-2}
5	568.335	9.685	5.42 x 10^{-3}	8.41 x 10^{-2}

Table7 Results of Polycarbonate Spur Gear

Sr. No.	Force (N)	Stress	Strain	Displacement
1	113.667	1.937	0.81 x 10^{-3}	1.29 x 10^{-2}
2	227.334	3.874	1.64 x 10^{-3}	2.58 x 10^{-2}
3	341.001	5.811	2.45 x 10^{-3}	3.86 x 10^{-2}
4	454.668	7.748	3.27 x 10^{-3}	5.15 x 10^{-2}
5	568.335	9.685	4.09 x 10^{-3}	6.44 x 10^{-2}

V. EXPERIMENTAL ANALYSIS

Experimental analysis we have done on Polariscope

5.1 The procedure for determining the direction of principal stresses at given point is a follows [17]

Use plane polarized arrangement

Use white light

Load the model in loading frame

Apply load of smaller values so that only black fringes are seen

The black fringe may be isoclinics or zero order isochromatics. In order to distinguish isoclinic from zero order isochromatics, rotate the polariser - analyser in locked position slightly. The fringes which move with the small rotation are the isoclinic which the fringes which remains stationary are the zero order isochromatics.

Once the isoclinics have been established as above, rotate the polariser-analyser jointly, so that the isoclinic passes through the point of interest.

Note down the angle through which the polariser have been rotated from the reference and this is the angle that one of the principal stresses makes with reference, other principal stress is perpendicular to it.

Table 5.1 Experimental Bending Stress Results of Polycarbonate Spur Gear

Sr. No.	Force (N)	Theoretical (N/mm2)	Experimental (N/mm2)	Error in %
11	113.667	2.03	2.07	1.93
22	227.334	4.07	4.19	2.86
23	341.001	6.10	6.17	1.13

Table 5.2 Experimental Bending Stress Results of Polycarbonate Spur Gear

Sr. No.	Force (N)	ANSYS 10 (N/mm2)	Experimental (N/mm2)	Error in %
1	113.667	1.937	2.07	6.42
2	227.334	3.874	4.19	7.54
3	341.001	5.811	6.17	5.81

Table 5.3 Experimental Strain Results of Polycarbonate Spur Gear

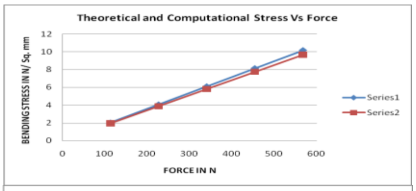
Sr. No.	Force (N)	Theoretical	Experimental	Error in %
1	113.667	0.73 x 10-3	0.75 x 10-3	2.66
2	227.334	1.48 x 10-3	1.52 x 10-3	2.63
3	341.001	2.21 x 10-3	2.24 x 10-3	1.33

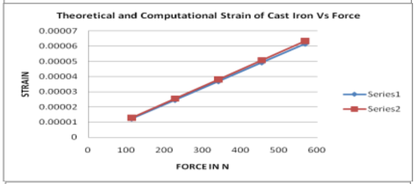
Table 5.4 Experimental Strain Results of Polycarbonate Spur Gear

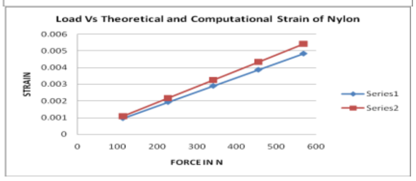
Sr. No.	Force (N)	ANSYS 10	Experimental	Error in %
1	113.667	0.81 x 10-3	0.75 x 10-3	7.40
2	227.334	1.64 x 10-3	1.52 x 10-3	7.31
3	341.001	2.45 x 10-3	2.24 x 10-3	8.57

VI. RESULTS AND DISCUSSION

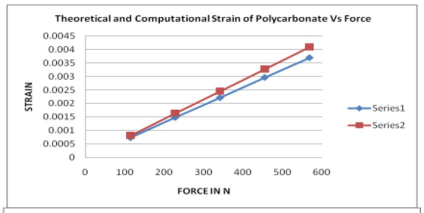
6.1 Graphs of Theoretical and ANSYS Results

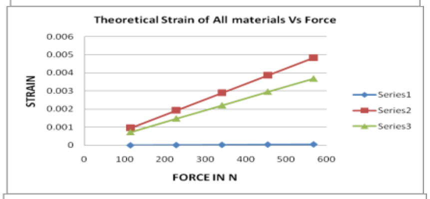


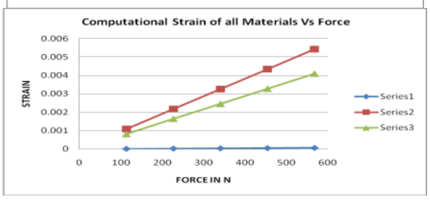




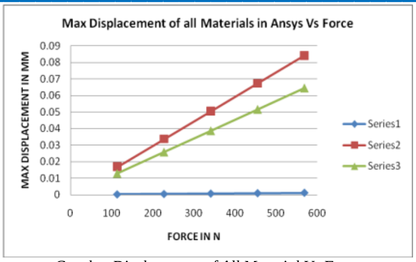
Graph a *Theory and Ansys StressVs Force*
Graph b *Theory and Ansys Strain Vs ForceCast Iron* ***Graph c*** *Theory and Ansys Strain Vs Force Nylon*







Graph d *Theory and Ansys StressVs Force Polycarbonate*
Graph e *Theory Strain of all material Vs Force Cast Iron* ***Graph f*** *Ansys Strain of All Material Vs Force Nylon*



Graph g Displacement of All Material Vs Force

6.2 Discussion

From the static analysis by increasing the force on the tooth edge it was observed that the bending stresses and strain values of the spur gear were increased.

Induced bending stress values were below the ultimate stress of Polycarbonate and Nylon spur gear, so safe design is possible. Also it was observed that density of Polycarbonate and Nylon material is less than the Cast Iron material. Minimum strain values were obtained for Polycarbonate spur gear compared with Nylon. Also it was observed that minimum displacement value was obtained for Polycarbonate spur gear compared with Nylon. According to the study, analysis and results we recommend the best plastic material is Polycarbonate and Polycarbonate Spur gears are suitable to safe and light weight design for the application of sugar cane juice machine under limited load conditions.

VII. CONCLUSIONS AND FUTURE SCOPE

7.1 Conclusions

The investigation result infers that there is a difference in a result of theoretical bending stress calculation and computational bending stress calculation (Error 4.58% – 4.81%).

The investigation result infers that there is a difference in a result of theoretical bending stress calculation and Experimental bending stress calculation (Error 1.13% – 2.86%). and Computational bending stress calculation and Experimental bending stress calculation (Error 5.81% – 7.54%).

Bending stress developed in a spur gear tooth subjected to a fixed load is independent of material properties.

It was observed that Strain and displacement of Gear tooth depends on material property E (Young's Modulus).

Minimum bending strain values were obtained for Cast Iron spur gear compared with Polycarbonate and Nylon.

(At the load of 113.667N the strain value was obtained in Cast Iron gear tooth 1.23 x 10-5 by theoretical Analysis, However at same load strain values were obtained in Polycarbonate and Nylon 0.73 x 10-3, 0.96 x 10-3 respectively)

It was observed that density of Polycarbonate and Nylon is less than Cast Iron material. So the Polycarbonate and Nylon materials are light weight compare to Cast Iron

It was observed that displacement value of Polycarbonate material is less than Nylon material.

Induced stress was below the Maximum Allowable stress observed in Polycarbonate and Nylon material at same load. (At the force of 113.667N, Induced stress obtained in Nylon and Polycarbonate material was 2.03 N/mm2 and 2.03 N/mm2).

According to study, analysis and results we recommend the best plastic material is Polycarbonate for safe and light weight design. Polycarbonate spur

7.2 Scope for further work

Gears of any material having circular root fillet design can be investigated using similar procedure. It is important because it is observed that use of circular root fillet increases the beam strength of gear tooth as compare to that in case of trochoidal root fillet.

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