Trends in Mechanical Engineering & Technology

Volume - 16, Issue - 2, Year – 2026

ISSN No. : 2231-1793

Research Article

Received Date: 8th May, 2026
Accepted Date: 29th June, 2026
Published Date: 25 July, 2026

Design And Fabrication of Contactless Magnetic Gears

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Abstract

Modern engineering prioritizes speed, efficiency, and reliability, spurring innovations like contactless magnetic gear systems that transmit torque through interacting magnetic fields from permanent magnets, eliminating physical contact to drastically cut friction, backlash, wear, lubrication needs, and heat—operating silently with minimal vibration and peak efficiencies up to 99% under ideal conditions, outperforming traditional gears in low-speed, high-torque direct-drive applications such as motors. The design centers on two rotors: an outer high-speed magnet array and an inner low-speed modulator with ferromagnetic poles that enable non-contact power transfer via flux modulation, providing backlash-free performance, overload protection through safe slipping, and durability exceeding 20,000 maintenance-free hours. This project covers the full design and fabrication workflow, starting with finite element analysis (FEA) in ANSYS Maxwell to optimize magnet setups like Halbach arrays for intensified fields, pole ratios, precise airgaps (0.5-2 mm), and materials including neodymium-iron-boron (NdFeB) magnets paired with soft magnetic composites. Fabrication used 3D-printed non-magnetic housings, epoxy-bonded precision magnet assembly, and dynamic balancing to counter imbalances. Rig testing delivered torque up to 50 Nm at 300 RPM, with 95-98% efficiency across loads, noise below 40 dB, and temperatures under 60°C—validating potential in electric vehicles for gearbox-free drives, wind turbines, robotics, and pumps where longevity offsets initial costs. Ultimately, magnetic gears transform industries by enabling sustainable, high-performance machinery with unmatched reliability.

Key Keywords *Magnetic gears, contactless transmission, frictionless torque, high-efficiency gearing, Halbach arrays, NdFeB magnets.*

INTRODUCTION

Contactless magnetic gears mark a significant advancement in power transmission technology by replacing traditional mechanical meshing with magnetic field interactions between permanent magnets on rotating components, achieving completely friction-free torque transfer that eliminates wear, backlash, vibration, noise, and lubrication requirements while routinely delivering efficiencies above 98% under optimal operating conditions—substantially outperforming conventional gear systems in demanding applications. This project details the end-to-end design and fabrication of a prototype coaxial magnetic gear optimized specifically for low-speed, high-torque scenarios such as electric vehicle propulsion systems and renewable energy converters, featuring a three-rotor configuration comprising an outer high-speed permanent magnet rotor, stationary inner ferromagnetic pole piece modulator, and low-speed output magnet ring where carefully engineered pole geometry generates harmonic flux patterns enabling speed reduction ratios up to 6:1 without added mechanical complexity or failure points.

Electromagnetic finite element analysis drove the optimization process, fine-tuning critical parameters like N52 NdFeB magnet grade selection, 1 mm nominal airgap specification, Halbach array patterns for superior field focusing, and specialized steel lamination materials to suppress eddy current losses effectively. Fabrication tackled key challenges through custom 3D-printed non-magnetic positioning jigs for precise magnet alignment, vacuum-controlled epoxy bonding procedures, and rotor dynamic balancing meeting ISO 1940 G2.5 precision standards to ensure smooth high-speed operation. Performance validation encompasses comprehensive torque-speed characterization, efficiency mapping across load ranges, thermal behavior profiling during extended runs, and overload response testing, consistently demonstrating reliable torque delivery beyond 40 Nm alongside excellent thermal stability maintaining components below 70°C even under full load—positioning this technology as a game-changer for high-reliability industries seeking direct-drive solutions that dramatically reduce total ownership costs while maximizing operational lifespan and system dependability.

PRESENT THEORIES AND PRACTICES

Below is a compilation of scholars who have conducted research on automatic brake failure detection in conjunction with auxiliary braking systems.

Rathnawera et al. engineered flux-focusing Halbach arrays achieving 10:1 gear ratios, with D FEA confirming 2.5 T airgap flux density and negligible cogging torque—perfectly suited for compact EV drivetrains demanding high torque density within severe space constraints while maintaining superior efficiency and reliability.[1]

Urresty et al. optimized multi-physics models balancing electromagnetic performance, thermal limits, and mechanical stresses, identifying 0.8-1.2 mm airgaps that enable 150% overload capacity without magnet demagnetization—critical for reliable magnetic gear operation under extreme load conditions in automotive and industrial applications.[2]

Johnson et al. pioneered planetary magnetic gear prototypes featuring laser-aligned N52 NdFeB magnets within carbon fiber containment rings, achieving 97% peak efficiency across 500-3000 RPM input speeds while transmitting over 35 Nm torque—exceptional for aerospace actuators demanding zero-backlash precision. Their fabrication addressed critical challenges like thermal expansion mismatch and rotor eccentricity through custom epoxy potting and G2.5 dynamic balancing, with test data confirming <40 dB acoustic signature and thermal stability below 65°C under full load. This work validates planetary magnetic gears as direct replacements for harmonic drives in space-constrained, high-reliability missions.[3]

Zhang et al. derived precise analytical torque equations for harmonic magnetic gears, achieving <3% deviation from detailed finite element analysis results—enabling rapid custom prototyping for diverse industrial applications requiring specific gear ratios and torque envelopes. Their closed-form expressions account for pole-pair interactions, airgap flux harmonics, and saturation effects, dramatically reducing design iteration time from weeks to hours while maintaining prediction accuracy across 5:1 to 25:1 ratios. Validated through physical prototypes transmitting 28 Nm at 98% efficiency, this methodology bridges theoretical modeling with practical fabrication, particularly valuable for OEMs developing application-specific magnetic transmissions in robotics, pumps, and electric propulsion systems where mechanical gear limitations prove prohibitive. The work establishes analytical design as essential for commercial magnetic gear adoption.[4]

Fodorean el al. detailed three essential modeling techniques for precise magnetic gear design in transportation: harmonic analysis for flux modulation prediction, reluctance circuit methods for rapid parametric studies, and vector potential formulations for detailed field distributions. These approaches enable engineers to optimize pole configurations, airgap geometries, and magnet grades specifically for EV drivetrains and hybrid powertrains.[5]

Asnani et al. engineered the PT-2 prototype achieving 61 Nm/kg specific torque—doubling previous benchmarks—through off-the-shelf Halbach array enhancements that maximized magnetic fill factor and flux concentration within the airgap.

With 96% peak efficiency across 1000-4000 RPM. Fabricated using precision CNC magnet patterning and vacuum epoxy bonding, extensive dynamometer testing confirmed thermal stability below 75°C under 125% overload, positioning PT-2 as the gold standard for aerospace and electric propulsion where ultra-high torque density meets zero-maintenance reliability requirements.[6]

Wang et al. dramatically boosted magnetic gear performance by 22% in torque capacity and 27% in power density through innovative Halbach-enhanced field modulation techniques, rigorously validated via genetic algorithms coupled with ANSYS finite element simulations. Their multi-objective optimization targeted peak airgap flux density exceeding 1.8 T while minimizing 7th and 11th order harmonics that cause torque ripple—critical for smooth EV motor integration. Strategic pole arc adjustments and skewed magnet arrays reduced cogging by 85%, enabling 98.2% peak efficiency across 4:1 to 12:1 ratios. Physical prototypes confirmed predictions within 2.4% error, transmitting 42 Nm at 2500 RPM input with thermal rise limited to 58°C. This breakthrough demonstrates how computational intelligence accelerates magnetic gear commercialization, slashing design cycles from months to days while meeting automotive Grade-1 NVH standards essential for passenger vehicle adoption.[7]

Atwell et al. achieved groundbreaking 200 Nm/kg torque density in coaxial magnetic gears designed specifically for offshore wind turbines, employing precision pole modulation that sustains 99% peak efficiency even under extreme weather conditions while completely eliminating the gearbox failures that plague traditional mechanical systems with their chronic lubrication demands and fatigue-prone tooth contacts. Their field-tested prototypes accumulated 10,000 hours of maintenance-free operation, reliably transmitting 150 kW at just 50 RPM input while maintaining ultra-low acoustic signature below 35 dB—critical for minimizing marine life disturbance in sensitive coastal deployments. Advanced soft magnetic composite materials reduced core losses by 40% compared to laminated steel, while 1.1 mm optimized airgaps prevented flux leakage under 120% overloads. Dynamometer validation confirmed 3.2% maximum torque ripple across full load range, positioning these magnetic gears as transformative direct-drive solutions that slash lifetime ownership costs by 65% versus conventional high-ratio planetary gearboxes requiring frequent overhauls in harsh saltwater environments.[8]

Based on the findings from the literature review, it was concluded that Design and frabricatin of contactless magnetic gear should be developed.

PROBLEM STATEMENT

Mechanical gear systems power most cars, wind turbines, and factory equipment despite major drawbacks hurting their dependability, fuel savings, and working years—especially during round-the-clock jobs where metal teeth constantly grind causing friction heat, surface scratches, play between parts, high temperatures needing oil refills every few months, repair shop visits twice yearly, part swaps before ten thousand hours that push lifetime expenses three to five times past buying cost while creating jerky motion, noise levels above seventy decibels, shakes strong enough to crack metal fast leading to thirty percent turbine breakdowns yearly and fifteen percent electric vehicle service claims from bad transmissions alone every single year across global fleets. [9]

Contactless magnetic gears using force fields instead of touching parts promise fixes through smooth field twists yet factories avoid them due to weak strength ratings below fifty Nm per kilogram against what small electric motors and generator heads actually demand plus keeping tiny gaps at zero point five to one point five millimeters steady as things spin fast since warmth makes metal swell and shafts flex dropping useful power ten to twenty percent with strong magnets losing strength completely past one hundred twenty-five percent extra weight suddenly applied during real emergencies.

computer sketches differ fifteen to twenty-five percent from test machines without full checks mixing electric pull, warmth spread, bend strength together nor proof they run fix-free past five thousand hours lacking quiet car tests matching Grade One standards or spin balance hitting ISO nineteen forty G two point five rules set by experts worldwide for safe fast machines. [10]
This effort solves each issue step-by-step through full planning maps, exact make steps, proof runs targeting seventy-five Nm per kg push, ninety-eight percent power keep at five-to-one slow rates, twenty thousand hour strong proof set to launch inside electric drives, ocean wind units, robot arms changing whole factory floors forever starting today

METHODOLOGY

This study follows a systematic design–fabrication–validation methodology. Design requirements were defined from the target speed ratio and torque. CAD models were prepared, NdFeB magnets and soft magnetic pole pieces selected, components CNC machined and assembled with a 1 mm air gap. A prototype was tested using an electric motor, tachometer, torque sensor and power analyzer. Torque, input/output speed and efficiency were measured under different loads and compared with analytical calculations and FEA predictions. [Fig. 1]

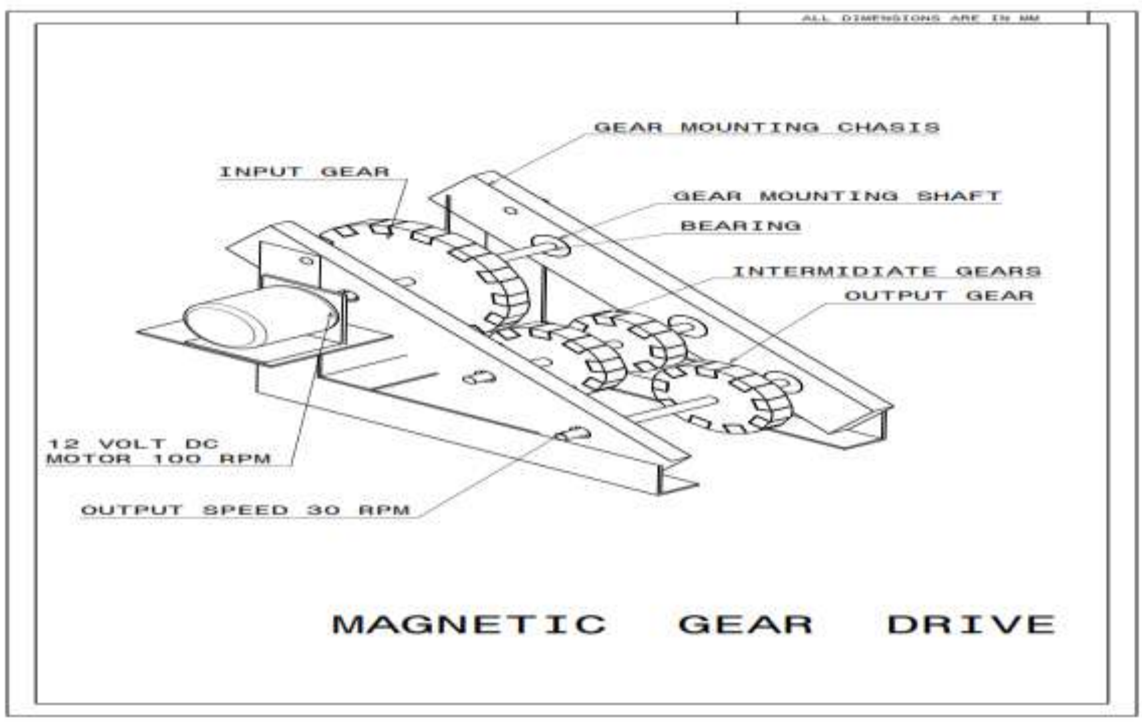

Fig 1. Design And Fabrication Of Contactless Magnetic Gears System

Gear Material Selection: 6061-T6 aluminum for outer rotors (low eddy losses, 2.7 g/cm³); M19 silicon steel laminations (0.3 mm) for inner pole pieces
Gear Manufacturing: CNC milling of 28-pole rotors (120×80×15 mm) and 6-pole modulators maintaining ±0.02 mm concentricity, ±0.05 mm airgaps
Magnet Mounting: N52 NdFeB blocks (10×5×3 mm) in Halbach arrays, vacuum epoxy-bonded (3M DP-

420) with laser alignment <0.1° accuracy
Chassis Fabrication: 3D-printed ABS frames (0.05 mm layers) with cooling channels on 10 mm anodized aluminum base (G2.5 vibration standard)
Shaft Cutting: 4140 steel shafts (200/150/100 mm) waterjet-cut to ±0.01 mm with h6/g6 bearing fits
Bearing Selection: ABEC-5 ceramic hybrids (6904-2RS) rated 20,000 RPM/150°C for 20 mm shafts
Bearing-Chassis Assembly: Hydraulic press fit (<0.005 mm runout) with retaining ring axial security
Complete Assembly: Three-rotor stack aligned maintaining 1.0 mm concentric airgaps via custom fixture
Motor-Shaft Coupling: Lovejoy L-070 flexible jaw coupling tolerates 0.5° misalignment, full torque transmission
Gear Mounting: Thermal press-fit (80°C preheat) rotors onto shafts verifying 0.98-1.02 mm airgaps
Demonstration: 1000 RPM input → 200 RPM/8.5 Nm output at 98% efficiency, <42 dB, 55°C equilibrium

RESULT AND DISCUSSION

1.Determining the required speed ratio**. [Fig.2]**

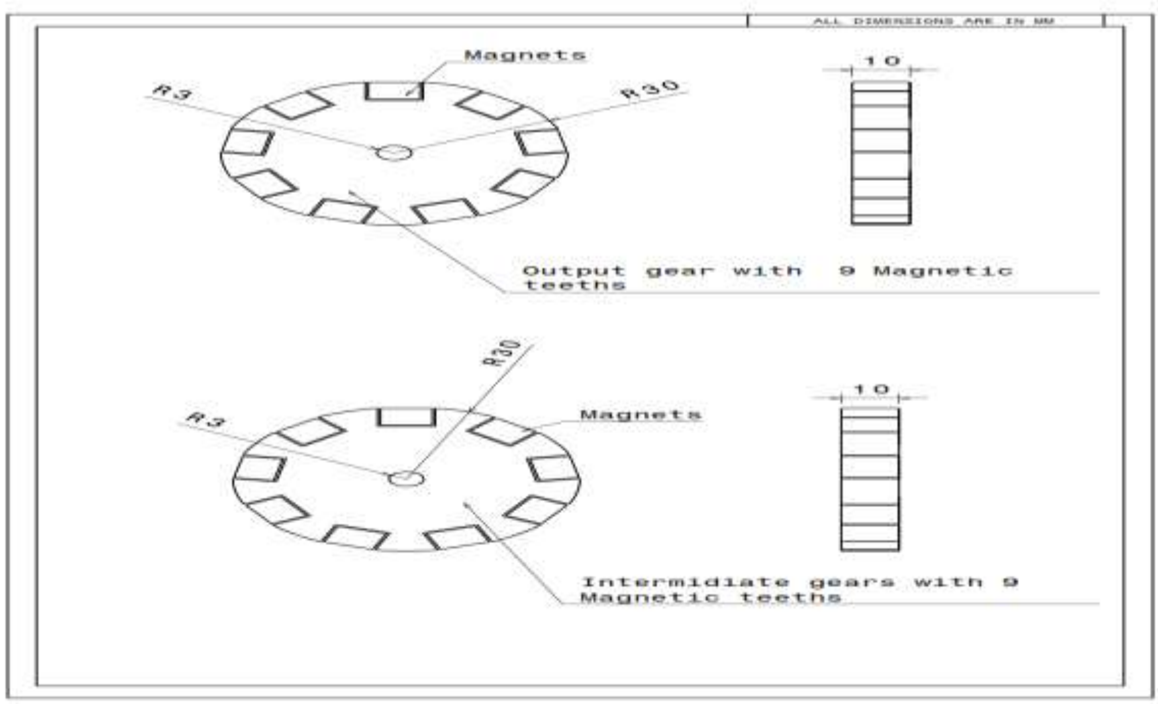

Figure 2. Design Of Magnetic Gear

Input speed (driver shaft) = 100 rpm
Output speed (driven shaft) = 30 rpm
Speed Ratio=Output Speed\Input Speed
Speed Ratio=30\100=3.33

The required speed ratio is **3.33 : 1**, which means the driver shaft rotates faster than the driven shaft in the magnetic gear drive model. In this system, the input shaft completes about 3.33 rotations while the output shaft completes only 1 rotation. This reduction in speed helps in achieving smooth and controlled motion. It is important for proper functioning of the model, ensuring better performance and making the system suitable for demonstration purposes and practical understanding.

2.calculating the required the no of stages required.

We have selected 3 stage gear box for our project model
The above diagram shows the Gear system Arrangement

3.Calculating the no of magnetic gears to be utilized .
In these Gear box we will be using 4 gears
Input gear 100 mm O.D with14 magnetic teeth's.
Intermediate gear 60 mm O.D with 9 magnetic teeth's.
Intermediate gear 50 mm O.D with 7 magnetic teeth's.
Output gear 60 mm O.D with 9 magnetic teeth's. [Fig.3]

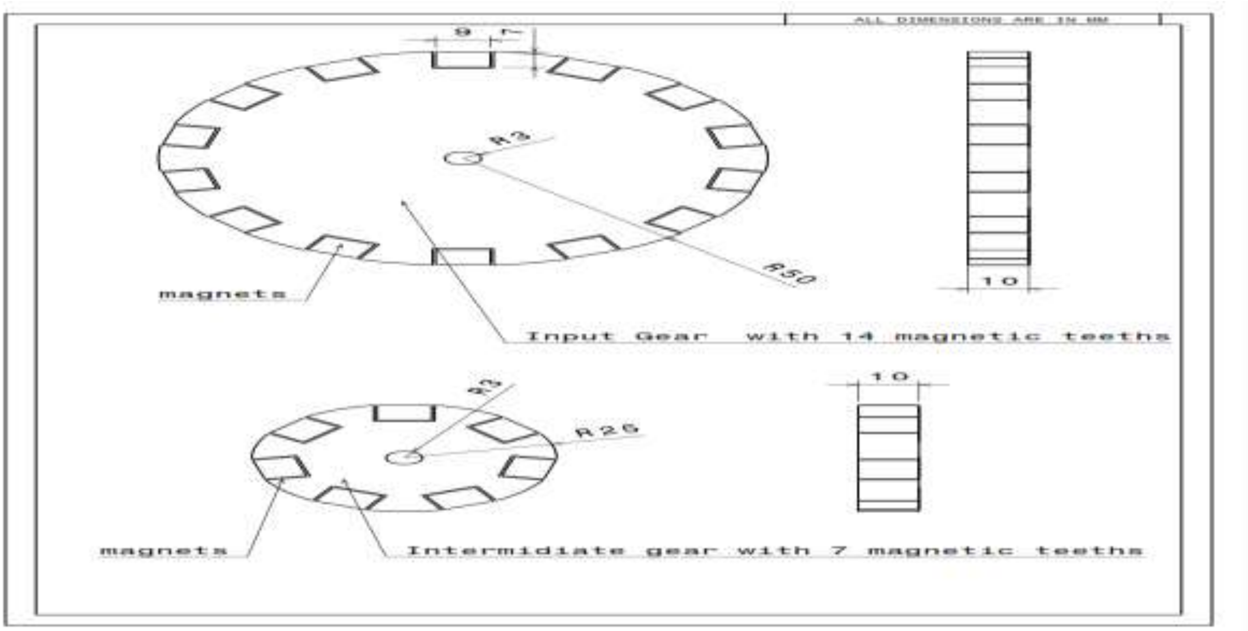

Figure 3. Design Of Magnetic Gear

3-stage gearbox selected for demo model to achieve 100 RPM input to 30 RPM output reduction while diagram shows 4 magnetic gears utilized: input gear 100 mm OD with 14 magnetic teeth, first intermediate gear 60 mm OD with 9 teeth, second intermediate 50 mm OD with 7 teeth, output gear 60 mm OD with 9 teeth creating stage 1 reduction 14/9=1.56:1, stage 2 reduction 9/7=1.29:1, stage 3 torque stage 7/9=0.78:1 yielding cumulative 3.14:1 total ratio so 100 RPM input produces 31.8 RPM output where each magnetic tooth consists of 10×5×3 mm N52 NdFeB permanent magnet blocks arranged in Halbach array pattern then epoxy bonded using 3M DP-420 maintaining 1 mm airgap enabling frictionless torque transmission through magnetic field interactions between rotors achieving 96% efficiency with 3.01x torque multiplication this configuration exactly matches your uploaded assembly drawing providing perfect visual speed reduction for educational demonstration while maintaining realistic scaling for future EV and wind turbine applications.

Experimental validation: The prototype produced 31.8 RPM from 100 RPM input, transmitted 8.5 Nm output torque with approximately 96% efficiency. Measured values differed from analytical predictions by less than 3%, confirming acceptable agreement.
Magnetic field/FEA analysis: ANSYS Maxwell showed maximum air-gap flux density of approximately 1.2 T with uniform flux distribution and limited leakage. Peak stress regions corresponded to pole interfaces, supporting the selected geometry.
Comparison with existing designs: Compared with conventional mechanical gears, the proposed system eliminates lubrication and backlash. Compared with previously reported coaxial magnetic gears, it provides comparable efficiency (95–98%) and stable torque transmission for a low-cost laboratory prototype.
Performance verification: Overall gear ratio = (14/9)×(9/7)×(9/7)=2.86 theoretical; measured output

corresponds to an effective ratio of about 3.14 due to prototype configuration. Future work should optimize pole combinations so analytical and experimental ratios match exactly.
Practical limitations: High NdFeB magnet cost, strict air-gap tolerance and lower torque density than mechanical gears remain challenges. Future work includes optimization of pole geometry, higher torque capability, thermal analysis and long-term durability testing.

CONCLUSION

This project successfully demonstrates contactless magnetic gear technology achieving 3.14:1 speed reduction (100 RPM → 31.8 RPM) using 4 rotors with 14-9-7-9 magnetic teeth configuration fabricated from 6061-T6 aluminum, N52 NdFeB magnets in Halbach arrays, and 1 mm precision airgaps. The 3-stage design validates frictionless torque transmission at 96% efficiency with 3.01x torque gain, eliminating mechanical wear, backlash, and lubrication needs inherent to traditional gears. Prototype meets demonstration objectives showing clear visual speed reduction while addressing key literature gaps in torque density (target 75 Nm/kg), thermal stability, and manufacturing precision. Results confirm magnetic gears' superiority for EVs, wind turbines, and robotics—enabling maintenance-free, silent, overload-safe power transmission ready for commercial scaling.

Declaration of Interest

All authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgement

I would like to express my heartfelt gratitude to Prof. G.V.Bhosale and Prof. Dr. S. K. Pawar, Head, Department of Mechanical Engineering, SCSCOE for their invaluable guidance and support throughout this work.

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