

# A cylindrical capacitive sensor (CCS) for both radial and axial motion measurements

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## Abstract

Conventional cylindrical capacitive sensors (CCS) are used only to measure the radial error motion of rotating machinery. However, axial error motion is also very important in rotating machines and it is very difficult to measure the axial motion due to the limited space. This paper presents a new CCS for both radial and axial motion measurements. The idea behind the new sensor is that the unused axial area of the CCS is exposed to measure the axial motion of a target. A theoretical model of the proposed CCS was derived. Based on the derived theoretical model, compensation methods to decouple the radial and axial motion measurements were proposed. In addition, an error analysis of the CCS was performed and a design rule was developed to guarantee the same accuracy in measuring both radial and axial motion measurements. Finally, a test rig and electronics for the proposed CCS were built and the effectiveness of the proposed CCS was verified through experiments and simulations. The developed CCS is expected not only to reduce the system complexity but also to afford a good balance between the radial and axial motion measurement accuracies.

**Keywords:** capacitive sensor, displacement measurement, rotating machinery

(Some figures in this article are in colour only in the electronic version)

## 1. Introduction

Smart sensor systems, particularly position measurement systems, are expected to play a significant role in the high-precision intelligent manufacturing system. For example, a feedback control is inevitable to ensure sufficient repeatability for the high-resolution positioning of semiconductor manufacturing systems [1]. In addition, usage of active bearings like active magnetic bearings is being increased to achieve higher precision and productivity [2]. In these systems, the position measurement systems not only affect the system performance, but also the system size and complexity.

Probe-type displacement sensors are highly sensitive to the surface quality of a target and these sensors require an additional algorithm to detect and compensate for the unnecessary signal induced by geometric errors [3, 4]. To

analyse an air-bearing spindle error motion, a cylindrical capacitive sensor (CCS) was introduced by Chapman as an alternative to the probe-type sensors [5]. It was verified that the CCS showed much better performance in rejecting the geometric errors of a rotor than probe-type sensors [6], and it can minimize the effects of geometric errors by adjusting the sensor angular size [7]. Also, an extended analysis of a multi-segment CCS was performed [8] and a CCS was applied to the rotor motion measurement of a small air conditioning compressor [9].

The CCS is used only for measuring the radial error motion of rotating machinery. However, axial error motion is also very important in rotating machines such as hard disc and machine tools and it is very difficult to measure the axial motion due to the limited space. Moreover, it is very hard to balance the accuracies of both the radial and axial error motion measurements.

# A Cylindrical Capacitive Sensor Ccs For Both Radial And

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### Table of Contents A Cylindrical Capacitive Sensor Ccs For Both Radial And

1. Understanding the eBook A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - The Rise of Digital Reading A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Advantages of eBooks Over Traditional Books
2. Identifying A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - User-Friendly Interface
4. Exploring eBook Recommendations from A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Personalized Recommendations
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And User Reviews and Ratings
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And and Bestseller Lists

5. Accessing A Cylindrical Capacitive Sensor Ccs For Both Radial And Free and Paid eBooks
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And Public Domain eBooks
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And eBook Subscription Services
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And Budget-Friendly Options
6. Navigating A Cylindrical Capacitive Sensor Ccs For Both Radial And eBook Formats
  - ePub, PDF, MOBI, and More
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And Compatibility with Devices
  - A Cylindrical Capacitive Sensor Ccs For Both Radial And Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Highlighting and Note-Taking A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Interactive Elements A Cylindrical Capacitive Sensor Ccs For Both Radial And
8. Staying Engaged with A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers A Cylindrical Capacitive Sensor Ccs For Both Radial And
9. Balancing eBooks and Physical Books A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection A Cylindrical Capacitive Sensor Ccs For Both Radial And
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Setting Reading Goals A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Fact-Checking eBook Content of A Cylindrical Capacitive Sensor Ccs For Both Radial And
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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web graad 10 ekonomie vraestel 1 11 2 uur punte 100 11 bladsye b o gautengse departement van onderwys provinsiale

eksamen ekonomie vraestel 1 tyd 11 2 uur punte 100 instruksies en inligting beantwoord drie vrae soos volg in die antwoordboek afdeling a verpligtend afdeling b beantwoord

**vraestelle pnhs** - Jun 28 2022

web vraestelle vir 2019 graad 8 2 taal gr 8 nov 2018 2 taal gr 8 nasienriglyne nov 2018 2 graad 8 afrikaans vraestel 2 taal en begrip 1 assessering voorbeeldvraestelle 1 en 3 graad 10 afrikaans huistaal 2013 2 besigheidstudies gr 10 1dbe 2018 besigheidstudies gr 10 2dbe 2018 gasvryheidstudies gr 10 junie 2018 gr10v2november

**millî eđitim bakanlıđı e denklik** - Mar 26 2022

web soru yurt dıřından gelen hangi belgelerden onay istenir yada hangi belgelere onay gereklidir cevap 30 05 2019 tarihli ve 30789 sayılı resmi gazetede yayımlanan denklik yönetmeliđi 5 madde ç bendine göre mezun durumda olanlar için apostille apostille yaptırmamıřsa İlgili Ülkenin eđitim bakanlıđı onayı ve dıř İřleri bakanlıđı onayı ya da

*graad 10 vraestelboek met memos wiskundeandibrand* - Feb 05 2023

web hierdie vraestelle dek ook die vrae wat in departementele graad 10 junie en november vraestelle voorgekom het vanaf 2010 tot 2019 dit is uiters volledig en bied uitstekende voorbereiding vir graad 10 leerders vir die junie en november eksamens

graad 10 my klaskamer idees en gedagtes uit n juffrou se pen - May 28 2022

web grondslagfase wiskunde assesserings laaste kwartaal isindebele isixhosa isizulu sepedi sesotho setswana tshivenda xitsonga tweetalig grade 4 7 june nov graad 4 7 junie en nov grade 4 tot 7 june en nov graad 3 6 9 november vraestelle studeer net - Mar 06 2023

web ons het oefen vraestelle en memorandum vir alle vakke vir graad 1 9 ons het departementele vraestelle vir graad 10 12 *graad 10 lewenswetenskappe september eksamen memo* - Feb 22 2022

web jun 28 2023 hierdie produk bestaan uit n aflaaibare graad 10 lewenswetenskappe september eksamen memo vraag 1 organiese verbindings basiese strukture van selle mitose plantweefsel diereweefsel vraag 2 plant en diersel chloroplaste vraag 3 mitose organiese en anoragniese verbindings die vraestel bestaan uit 7 bladsye vir 65 punte

**vraestelle wiskunderocks** - Oct 01 2022

web vraestel 2 v2 februarie maart 2010 2019 v2 junie 2015 2019 vraestelle graad 8 junie september november graad 9 junie september graad 10 vraestel 1 junie 2012 2018 vraestel 2 november 2012 2017 graad 11 vraestel 1 junie 2012 2018 vraestel 2 november 2012 2017 graad 12 vraestel 1 v1 februarie maart 2010 2019 v1 junie 2016 2019