

# 行政院國家科學委員會專題研究計畫成果報告

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## 一、中文摘要

帶有離心調速器之旋轉機械(如透平)是重要的,常見的旋轉機械。迄今未有此種系統的詳盡之規則及渾沌動力分析,本計劃擬對此加以研究。我們探討一帶離心調速器之旋轉機械受到兩種不同型式之干擾所產生的動態行為。由李亞普諾夫直接法可求得系統平衡點的穩定條件。一個餘維數分歧分析應用於自治系統的退化點後,發現系統存在著 Hopf 分歧行為。由增量諧波平衡法(IHB)和多變量的福洛開理論有效地求得三維非自治系統的穩態響應。此外,藉相位圖、功率譜法、龐加萊映射法(Poincaré map)及李亞普諾夫指數可觀察到周期性、擬周期性及渾沌運動。

最後,在全局分析中,系統每個吸引子之吸引區由戈正銘與李三祈得出的改良式內插胞映射法(modified interpolated cell mapping)求得。

**關鍵詞：**離心調速器、動力分析、渾沌、旋轉機械

## 二、英文摘要

Rotating machines with centrifugal governor, e.g. turbines, are important and familiar rotating machines. Up to now, the detailed regular and chaotic dynamic analysis of such machine are absent. In this report, this subject are studied. The dynamic behaviors of a rotational machine with centrifugal governor which is subjected by two different forms of external disturbance are studied in the report. The Lyapunov direct method is applied to obtain conditions

of stability of the equilibrium points of the system. A codimension one bifurcation analysis for the autonomous system is carried out near the degenerate point. It is found that Hopf bifurcation occurs in the system. The incremental harmonic balance (IHB) method combined with multi-variable Floquet theory has been effectively applied to obtain the steady state responses of the three-dimensional nonautonomous system. Besides, phase diagrams, power spectra, Poincaré maps, and Lyapunov exponents are presented to observe periodic, quasiperiodic and chaotic motions. Finally, for global analysis, the basins of attraction of each attractors of the system are located by employing the modified interpolated cell mapping (MICM) method given by Zheng-Ming Ge and Sann-Chie Lee.

**Keywords:** centrifugal governor, dynamic analysis, chaos, rotating machine

## 三、緣由與目的

**緣由：**

渾沌現象是非線性動力學中的一項重大發現。渾沌現象之基本行為及背景理論在各領域已有甚多專書, Guckenheimer[1], Moon[2], Wiggins[3], Nayfeh[4], Hilborn[5], 曾做了比較完整的回顧總結, 而國內董必正教授[6-9]也有深入之研究。在渾沌尚未及研究前國內外對陀螺運動之研究已有相當可觀的成果[10-17], 但是目前對陀螺系統的渾沌行為討論並不多見, Leipnik and Newton[18]曾研究過具有線性反饋控制之剛體運動的渾沌現象, 但 Leipnik and

Newton 的研究僅指出其存在兩個怪吸引子，最近戈正銘等對這方面之研究有不少成果，這些成果已發表於國際著名期刊 [19-28]，對於如此重要的問題亟需加以注意和研究討論。本計劃依此精神，延續先前之研究期使研究結果更為完備，以精確的非線性運動微分方程作為根據，作理論及數值分析，故具有一定的實際與理論價值。

#### 目的:

帶離心調速器之旋轉機械為重要的，常見的旋轉機械。前人或以線性化方程加以粗略研究，或雖以非線性方程研究，但卻過於簡化。至於渾沌行為則未見有人研究過，現擬考慮較精確之非線性動力方程，以詳細研究其規則與渾沌行為，此結果對此種系統之設計與運轉有重大的實際指導意義。就非線性動力學而言，也有其一定的學術價值。

#### 四、結果與討論

##### 結果:

1. 採用拉格朗日運動方程式導出帶離心圓調速器的旋轉機械的運動微分方程組，它們是三個一階非線性微分方程所組成的非自治系統，再將此方程組無因次化。
2. 採用李雅普諾夫直接法得出系統平衡位置的穩定與不穩定的條件。
3. 用中心流形及標準型理論在自治系統的退化點得出其 Hopf 分歧行為。
4. 採用增量諧波平衡(IHB)法結合多變量福洛開理論有效地得出三維非自治系統的穩態解。
5. 以數值計算法得出相圖，功率譜，分歧圖，龐伽萊映射及李雅普諾夫指數，用來研究周期運動，準周期運動和渾沌運動的行為。最後用戈正銘與李三祈發展的改良式內插胞映射(MICM)法將系統做整體分析(global analysis)，得到各個吸引子的吸引區圖，其中包括碎形

(fractal)圖。

##### 討論:

本研究得出一個新的三維自治系統 (autonomous system) 之渾沌現象，十分可喜。我們知道由常微分方程表達的連續自治系統中出現渾沌現象者不多。故此一自治系統之渾沌值得做進一步之研究。

#### 五、計畫成果自評

1. 所得結果可對未來設計與運轉帶離心調速器之旋轉機械系統提供較可靠之理論依據。
2. 所得結果在非線性動力學方面具有學術價值。

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# 行政院國家科學委員會補助專題研究計畫成果報告

帶離心調速器之旋轉機械的規則與渾沌動力分析

Regular and Chaotic Dynamics of the Rotational  
Machine with Centrifugal Governor

計畫類別： 個別型計畫          整合型計畫

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