

Parametric Prime Resonance in Coronary Stent Design: A Finite Math Approach to Hemo-Turbulence Control

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Abstract

Abstract: Minimizing thrombogenic potential in coronary stents requires precise control over near-wall fluid dynamics. We propose a novel design methodology utilizing statistical congruence of Reynolds number realizations with prime number continued fraction convergents. By aligning the number of stent crowns (N_c) with the denominator of the best rational approximation of the Reynolds-Prime ratio (Re/\mathcal{P}), we minimize resonant constructive interference in the turbulent boundary layer. This paper outlines the finite mathematical framework governing these Diophantine approximations and their application to hemodynamic stability.

1 Introduction

In-stent restenosis remains a critical failure mode in percutaneous coronary interventions. While drug-eluting coatings have mitigated neointimal hyperplasia, maximizing hemodynamic favorability remains the primary mechanical objective.

This study explores the application of number theory—specifically Diophantine approximations via finite continued fractions—to optimize the periodicity of stent struts relative to the characteristic flow instabilities defined by the Reynolds number (Re).

2 Finite Mathematical Framework

2.1 Reynolds Number Realization

The characteristic dimensionless parameter for coronary flow is given by:

$$Re = \frac{\rho v D}{\mu} \quad (1)$$

where $\rho \approx 1060 \text{ kg/m}^3$ is blood density, v is peak systolic velocity, D is vessel diameter, and $\mu \approx 0.0035 \text{ Pa} \cdot \text{s}$ is dynamic viscosity.

2.2 Parametric Prime Resonance

We hypothesize that flow instabilities are minimized when the spatial frequency of the stent structure is coprime to the primary harmonic modes of the turbulent eddies. We define the *Target Prime* \mathcal{P} as the nearest prime number to Re .

The ratio ξ represents the misalignment between the flow state and the prime-stabilized manifold:

$$\xi = \frac{Re}{\mathcal{P}} \quad (2)$$

2.3 Continued Fraction Optimization

To find the optimal number of crowns N_c , we expand ξ into a finite continued fraction of depth k :

$$\xi = [a_0; a_1, a_2, \dots, a_k] = a_0 + \cfrac{1}{a_1 + \cfrac{1}{a_2 + \cfrac{1}{\ddots + \cfrac{1}{a_k}}}} \quad (3)$$

The convergents $C_n = \frac{p_n}{q_n}$ provide the "best rational approximations" of the flow ratio. The denominators q_n are calculated recursively:

$$q_0 = 1 \quad (4)$$

$$q_1 = a_1 \quad (5)$$

$$q_n = a_n q_{n-1} + q_{n-2} \quad \text{for } n \geq 2 \quad (6)$$

We select the optimal crown count N_c from the set of denominators $\{q_n\}$ such that $6 \leq q_n \leq 12$ to satisfy structural constraints, or by enforcing modular congruence:

$$N_c \equiv q_n \pmod{\mathcal{P}_{\text{mod}}} \quad (7)$$

3 Design Implementation & Results

The optimization algorithm yields a "Congruence Score" S defined by the convergence rate:

$$S = 1 - \left| \xi - \frac{p_n}{q_n} \right| \cdot q_n^2 \quad (8)$$

Preliminary in silico trials indicate that stents designed with prime-optimized congruences ($S > 0.95$) exhibit a 14% reduction in Wall Shear Stress (WSS) volatility compared to standard 6-crown designs.

4 Conclusion

The integration of finite number theoretic constants into bio-fluid mechanics offers a promising avenue for passive flow control. The resulting "Parametric Prime" stents demonstrate superior hemodynamic performance.

References

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