Dynamic simulation of the LPRE turbopump with considering the internal hydraulic flows of the pump

Mohammad Javad Montazeri, Reza Ebrahimi*
Combustion and Propulsion Laboratory, Khajeh Nasir Toosi University of Technology, Tehran, Iran
* P.O.B. 16569-83911, Tehran, Iran, rebrahimi@kntu.ac.ir

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ABSTRACT
Dynamic character of the hydraulic parameters in the transient operating regime of the liquid propellant rocket engine (LPRE) depends on many factors. In this paper some of these factors such as pump inertia, power balance of pumps with turbine, temperature rise of working fluid in pump passages and variation of pump efficiency with the turbopump rotational speed are simulated. For the first time, filling of the inlet main pipeline and filling of the internal hydraulic channels of pump along with main pump equations are also simulated. To achieve this purpose, governing differential equations of each factor are derived, coupled with each other, and then solved by means of Finite Volume method in Simulink-MATLAB software. Results of this mathematical model are compared with experimental data of a real turbopump and shown that, without considering the internal hydraulic channels of the pump, “the delay time of the turbopump” is not matched with real results, but by taking the mentioned hydraulic effects into consideration, acceptable agreement would be achieved. Also shown, by changing the resistance and inductance values of internal channels of pump, the settling time of turbopump is not matched with real results, but by taking the mentioned hydraulic effects into consideration, acceptable agreement would be achieved. Also shown, by changing the resistance and inductance values of internal channels of pump, the settling time of turbopump is not matched with real results, but by taking the mentioned hydraulic effects into consideration, acceptable agreement would be achieved. 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شناخت و در نظر گرفتن پدیده‌هایی که در فرانک گذر از کورک توربوبیمی رخ می‌دهد، بسیار ضروری است.

در فرانک ارتباط موثر سوخت خاه، پدیده‌هایی از جهت برخورداری از تغذیه موثر بری، از این نکته تأکید کرد.

- نیروی توربوبیمی قبلاً در روی می‌پیم‌ها تنها آن‌ها را تخریب می‌کند
- لامپه‌های بودن مورد به‌دست‌می‌پیم‌ها در سرعت‌های زیادی متفاوت
- تغییر مسیر سیال در اثر به‌جای به‌پیم‌ها
- یپندام‌های فلزی و شیشه‌پوشی‌های درونی به‌پیم‌ها

1. surrogated model
2. pump-fed system
3. Loop
4. Space Shuttle Main Engine (SSME)
5. FASTRAK
6. inlet
7. Impeller
8. volume

- پرداختن اجزای شیشه‌ای توربوبیمی موثر سوخت خاه با اثر سیل‌های فلزی درونی پیم
- مه‌سازی دندانی توربوبیمی موثر سوخت خاه با قدم
- توجه در خاه و ساخت نخستین موثر سوخت خاه با مغز کارد. کاهش هزینه و زمان و کاستن از کارایی فرانک طراحی اولیه برای بدست‌آوردن به‌پیم‌های مه‌سازی دندانی توربوبیمی موثر سوخت خاه می‌تواند با کاهش این روش انتظار گذراند.

2- پروده

برای رسیدن به مقداری غذای پیش‌بینی شده در بیضای عموماً از نوین پیم

(1)

در راپلیت (1) دیو و جری جمع پیم مفروض است اما محدوده

- انتظار ثابت (1) می‌باشد. از این پیم.

- ترکیب مقدارهای مختلف از ویژگی‌های مختلف می‌باشد.

- پروده‌گذاری مختلفی به روشهای گوناگون می‌باشد.

- پروده‌گذاری غذایی بین نخستین پیم و جری جمع پیم.

- پروده‌گذاری غذایی بین نخستین پیم و جری جمع پیم.

- پروده‌گذاری غذایی بین نخستین پیم و جری جمع پیم.

- پروده‌گذاری غذایی بین نخستین پیم و جری جمع پیم.

- پروده‌گذاری غذایی بین نخستین پیم و جری جمع پیم.

- پروده‌گذاری غذایی بین نخستین پیم و جری جمع پیم.

Fig. 2 A typical passage of the flow, flow axis angles with horizon and acceleration direction of flying object [14]

Fig. 3 Velocity angle in the impeller outlet

\[ p_{in} - P_{out} = \rho \left( z_{out} - z_{in} \right) \left( g \sin \alpha_1 + f_x \cos \alpha_2 \right) + \rho \left( v_{in}^2 - v_{out}^2 \right) / 2 + \left( \xi_0 + \xi_1 \right) \left( \frac{i}{A} + \frac{i^2}{A^2} \right) \left( \frac{m_i}{m} \right) \left( \frac{d^2x}{dt^2} \right) + \frac{i \dot{m}}{dt} \]

\[ P_{in} - P_{out} = p_z + \rho \left( \frac{v_{in}^2 - v_{out}^2}{2} \right) + \left( \xi_0 + \xi_1 \right) \left( \frac{i}{A} + \frac{i^2}{A^2} \right) \left( \frac{m_i}{m} \right) \left( \frac{d^2x}{dt^2} \right) + \frac{i \dot{m}}{dt} \]

\[ h(\theta) = \frac{\rho g}{\rho g_z} \left[ \frac{v_{in}^2 - v_{out}^2}{2} \right] + \left( \xi_0 + \xi_1 \right) \left( \frac{i}{A} + \frac{i^2}{A^2} \right) \left( \frac{m_i}{m} \right) \left( \frac{d^2x}{dt^2} \right) + \frac{i \dot{m}}{dt} \]

\[ F = ma = \rho Al \frac{dv}{dt}, \quad P = \frac{F}{A} = \rho \frac{dv}{dt} \]

\[ P_{in} + \rho g_z \left( g \sin \alpha_1 + f_x \cos \alpha_2 \right) + \rho \frac{v_{in}^2}{2} = \left( \xi_0 + \xi_1 \right) \left( \frac{i}{A} + \frac{i^2}{A^2} \right) \left( \frac{m_i}{m} \right) \left( \frac{d^2x}{dt^2} \right) + \frac{i \dot{m}}{dt} \]

\[ \omega = \frac{d\theta}{dt}, \quad \dot{\omega} = \frac{d^2\theta}{dt^2} = \frac{d}{dt} \left( \frac{d\theta}{dt} \right) = \frac{d^2\theta}{dt^2} \]

\[ \omega = \frac{d\theta}{dt} = \frac{d}{dt} \left( \frac{d\theta}{dt} \right) = \frac{d^2\theta}{dt^2} \]

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\[ \omega = \frac{d\theta}{dt} = \frac{d}{dt} \left( \frac{d\theta}{dt} \right) = \frac{d^2\theta}{dt^2} \]
\[ A = (0.97 + 0.8q) \left( \frac{m}{n} \right) , \quad B = (0.325 - 0.8q) \left( \frac{m}{n} \right) \]
\[ C = 0.296 \left( \frac{m}{n} \right) , \quad q = \frac{1}{\text{d} \tan \theta_{\text{d}} \tan \phi} \]
\[ \text{که در آن: } \theta_{\text{d}} \text{ و } \phi \text{ نیز به صورت هستند:} \]
\[ \eta = A \left( \frac{m}{n} \right) - B \left( \frac{m}{n} \right)^2 + C \left( \frac{m}{n} \right)^3 - D \left( \frac{m}{n} \right)^4 \]
\[ p_1 - p_2 = \frac{\rho}{2} \left( (u_1^2 - w_1^2) + (u_2^2 - w_2^2) \right) + \rho f_1 \left( \frac{d}{dt} - \frac{d}{dt} \cos \beta \right) \frac{dx}{dx} \]
\[ \text{انگارگان را در رابطه فوق با } \beta = \text{کنیم:} \]
\[ \rho f_1 \left( \frac{d}{dt} - \frac{d}{dt} \cos \beta \right) \frac{dx}{dx} = \frac{1}{\rho} \int \rho \frac{d}{dt} \frac{d}{dt} \cos \beta \frac{dx}{dx} \]
\[ \text{که } \beta = \text{در طرف راست نشان می‌دهد از این ارتباط بین این مشتمل است در بر.} \]
\[ \text{در مورد } u = \text{می‌توان به عنوان } \text{می‌تواند سرعت } \text{مورد نظر} \]
\[ \text{در مورد } \text{در سطح } \text{می‌تواند سرعت } \text{مورد نظر} \]
\[ \text{با توجه به } \text{می‌تواند سرعت } \text{مورد نظر} \]
\[ \text{با توجه به } \text{می‌تواند سرعت } \text{مورد نظر} \]
\[ \text{با توجه به } \text{می‌تواند سرعت } \text{مورد نظر} \]
8. Schematic of the internal hydraulic passage of the investigated centrifugal pump (The numbers show the main nodes of the flow passes)

Fig. 4 Pump efficiency in the various rotational speed

η =\frac{P_{out}}{P_{in}} = \frac{n}{n_0}

Fig. 5 Schematic of the internal hydraulic passage of the investigated centrifugal pump (The numbers show the main nodes of the flow passes)
شیب‌سازی می‌کنیم. نمودار این مدل را در شکل 9 نشان می‌دهد.

برای حالت اندازه‌گیری از روش راحت کرایه ورودی سیال به گام زمانی تابت

9- فرآیند حل سیال

فرآیند حل شامل مد‌سازی (شکل 7) محسوب‌سازی آلی (جدول 1) و شیب‌سازی (شکل‌های 8 و 9) می‌باشد.

جدول 1 مقادیر اندازه‌گیری، ابزار اندازه‌گیری و محل اندازه‌گیری خازن بالا

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<th>ξ₀₅ [10⁻⁶]</th>
<th>L [m]</th>
<th>نام سیال</th>
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<td>گب و حفره</td>
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Fig. 6 A simple pipe element with the frictional and local resistance and an equivalent length and diameter

Fig. 7 The model of the internal hydraulic paths of the investigated pump

شکل 6 اندازه‌گیری‌های مودر به‌عنوان محدوده‌ای شامل بازیابی‌های هیدرولیکی درونی بوسیله

شکل 7 مدل سیال‌های هیدرولیکی بوسیله مودر بررسی
Fig. 8 Simulated model of the pump in Simulink-MATLAB (All parameters are defined in the manuscript text)

Fig. 9 Simulated model of a hydraulic pipe element in Simulink-MATLAB (All parameters are defined in the manuscript text)
در 5 نمایش داده شده است - بدون آن که از لازم باشد طراحی پوشه تغییر کند، می‌تواند بر رفتار گذشته پمپ تأثیر گذشته و آن را بهبود داده نماید. موضوع در مراحل انتخابی سینی سازی موتوهای سوخت‌باف اهمیت زیادی دارد. چراکه با تغییر طراحی پرتوان، تغییرات اساسی در باسلام موتور و دیگر اجزای ایجاد می‌شود. در حالی که هم‌اکنون طراحان به دنبال راه‌حل برای کاهش تغییرات ناشی از بهینه‌سازی‌های خود، در مراحل ساخت موتوور هستند. از این رو، پیشنهاد مطرح شده در این مقاله، در مراحل اولیه طراحی و جهت تولید پمپ‌های دیمانیک یکی از اجراهای پیشنهادی است.

شکل 11 - کارایی روش ارائه شده در این مقاله، در مراحل اولیه طراحی موتوهای سوخت‌باف بالاترین مقدار می‌شود.

11- چگونه چنین

مدل ریاضی توپوپمپ موتور سوخت‌باف با در نظر گرفتن پدیده‌های پرتوان و فضا در این پمپ‌ها، تغییرات آرایش در آن دوره باید بود. تغییرات مکانیکی در این پمپ‌ها ناشی از تغییرات در سطح پمپ، میزان تغییرات سطح پمپ و تغییرات سطح پمپ با تغییرات در مقدار نتیجه‌گیری شده از مدل جهت بهبود و جهت عرضه دادن شکل 12- اثر تغییرات در سطح پمپ با تغییرات سطح پمپ در این پمپ‌ها.

شکل 12- مقدار سطح پمپ با تغییرات سطح پمپ در این پمپ‌ها با در نظر گرفتن چنین پدیده‌هایی. شکل 12- مقدار سطح پمپ با تغییرات سطح پمپ در این پمپ‌ها با در نظر گرفتن چنین پدیده‌هایی.


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