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The development of power-law preconditioning approach for simulation of unsteady viscoelastic flows

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ABSTRACT: One of the particular features of viscoelastic liquids in unstable shear flows is the damping oscillatory behavior in the velocity field without imposing external force and oscillation. This behavior is seen because of the elastic property of the liquid. In the present paper, for the first time, the preconditioning method of local stress censor has been employed for numerically simulating unstable viscoelastic liquids passing through fixed parallel plates. In this regard, the Maxwell model has been used. In this method, by adding fake time derivation to governing equation, hyperbolic equations will be generated. By obtaining the preconditioning matrix of these equations corrected locally through the power relation of stress field and employing binary algorithm for time including inner and outer loop, solving incompressible unsteady flows can be possible in the form of artificial compressible flows. In order to converge the inner loop, the four-step Vossooghifar's method has been implemented. Equations were discretized through the finite difference and shifted network. Calculation of unsteady viscoelastic flows has been performed for various Reynolds numbers, Weissenberg numbers and viscosity ratios have been presented. The results are in good agreement with the numerical results. Results of the convergence rate indicate that the locally preconditioning power censor method is the appropriate one for a viscosity ratio lower than 0.5 demonstrating a higher convergence rate and reduced time cost of calculations.

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1- Introduction

Researchers are always looking for numerical methods for simulating unsteady viscoelastic flows indicating appropriate steady behavior, higher convergence rate, low calculation error, and time-effective calculation time. In equations of incompressible flows which are a kind of parabolic-elliptic equations, there is no relation between continuity and momentum equations in terms of pressure. Incompressible unsteady equations are transferred to hyperbolic equations by adding an unphysical continuity equation. This method is known as the artificial compressible method [1]. Torkel [1] added an unphysical term to the momentum equations which is known as the preconditioning method. The preconditioning power method utilizing a preconditioning matrix with a local velocity censor was introduced by Esfahanian and Akbarzade [2]. The preconditioning power method utilizing a preconditioning matrix with a local velocity sensor was used to simulate unsteady and steady flow, and laminar and turbulent flow around an airfoil which indicated a higher convergence rate and lower calculation time [3]. Sato and Richardson employed Oldroyd-B and UCM to solve unsteady Poiseville viscoelastic flow [4]. In the present research, the preconditioning power method to simulate unsteady developing viscoelastic flow passing through fixed parallel plates for the first time.

2- Methodology

Preconditioning power model is implemented to simulate steady flow equations in which any progressive method can be used to discretized [3]. In this study, Vossoghifar's four-step method using preconditioning local censor in the stress field has been employed to modify the inner time loop. For solving incompressible unsteady flows by preconditioning power method, it is necessary to add implicitly real-time derivation with second-order accuracy to steady flow equations in the regressive form [5]. In this way, with a converging solution in virtual time, it is possible to solve equations in real-time through a binary-time algorithm [6]. According to the concept of the implicit method, there is no limitation in choosing the time step in terms of the stability of the method. The real-time step is just depending on the accuracy of the problem. To solve the governing equations, the finite element method with the shifted grid is used. For the evaluation of unsteady flow, local pressure and local velocity software have been employed. To discretize, equations (1) to (3) have been used [3].

In equations (1) to (3), K varies from 1 to 4 and δ_K is a constant coefficient in Vossooghi method in which for K=1,

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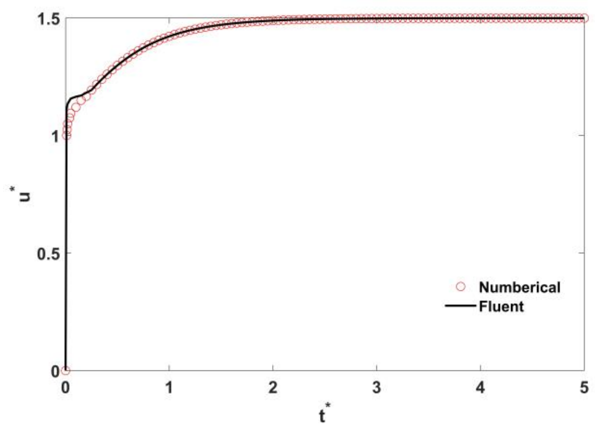

Fig. 1. Comparison of time variation of the u-velocity at $x=9$ and $y=1$ for $\mathrm{Re}=10$ and $\beta=1$ by solving the fluent.

Table 1. Effect of the locally power-law PM of stress sensor on convergence rate unsteady flow of viscoelastic fluid passing between tow fixed parallel plates

Mode number	1	2	3	4	5	6
Re	10	10	10	10	5	20
Wi	1	1	5	1	1	1
Viscosity ratio	0	25	25	50	25	25
Reducing the number of iterations compared to the pressure sensor power preconditioning method (~%)	63	21	41	-4	37	72
Reducing the number of iterations compared to the speed sensor power preconditioning method (~%)	23	3	3	3	7	2

δ_K is $2^{\frac{1}{3}}-1$ and for other k, it is $\frac{2}{3}-\frac{2^{\frac{1}{3}}}{3}$. The superscripts n and N indicate virtual and real-times.

$$
\begin{aligned}
&\mathbf{V}^0=\mathbf{V}^n\\
&\mathbf{V}^K=\mathbf{V}^{K-1}+\frac{2\delta_K\Delta t_a\Delta t}{2\Delta t+3\Delta t_a}\left\{-\vec{\nabla}p+\frac{\beta}{\mathrm{Re}}\nabla^2\mathbf{V}+\vec{\nabla}.\boldsymbol{\tau}-\mathbf{V}.\nabla\mathbf{V}\right.\\
&\left.-\frac{3\mathbf{V}^n-4\mathbf{V}^N+\mathbf{V}^{N-1}}{2\Delta t}-\frac{\alpha\mathbf{V}}{c^2}\frac{\partial p}{\partial t_a}\right\}^{K-1}\\
&\mathbf{V}^{n+1}=\mathbf{V}^4
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
&\boldsymbol{\tau}^0=\boldsymbol{\tau}^n\\
&\boldsymbol{\tau}^K=\boldsymbol{\tau}^{K-1}+\frac{2\delta_K\Delta t}{(2\Delta t+3\ \mathrm{Wi})}\left\{\frac{(1-\beta)}{\mathrm{Re}}\gamma_{(1)}\right.\\
&\left.-\mathrm{Wi}\left(\frac{3\boldsymbol{\tau}^n-4\boldsymbol{\tau}^N+\boldsymbol{\tau}^{N-1}}{2\Delta t}\right)-\boldsymbol{\tau}^n\right\}^{K-1}\\
&\boldsymbol{\tau}^{n+1}=\boldsymbol{\tau}^4
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
&p^0=p^n\\
&p^K=p^{K-1}-\left(\delta_K\Delta t_a c^2\right)\nabla.\mathbf{V}^{K-1}\\
&p^{n+1}=p^4
\end{aligned}
\tag{3}
$$

3- Results and Discussion

In this study, MATLAB has been used for simulation. In order to evaluate the results, analytical solutions cannot be employed for unsteady incompressible viscoelastic and Newtonian liquids passing through parallel plates in fully developed flows in references [7]. In order to validation of the present results, Fluent software has been used for $\beta=1$ (Newtonian fluids) and $\mathrm{Re}=10$ according to Figure 1. From Figure 1, it can be concluded that the results are in good agreement with the numerical results of Fluent. Figure 2 shows the effect of different preconditioning methods on the convergence rate for unsteady flows of viscoelastic fluid with $\mathrm{Re}=10$, $\mathrm{Wi}=1$ and $\beta=0.25$,passing between two fixed parallel planes. In this figure, the method of preconditioning the power of the stress sensor has the stability of the numerical solution and the increase of the convergence rate from the other methods mentioned in the viscosity ratio less than 0.5.

Table 1 represents the effect of the locally power-law PM of stress sensor on convergence rate unsteady flow of viscoelastic fluid passing between tow fixed parallel plates. To calculate the convergence rate, a reduction in the percentage of the number of iterations has been approximately considered. With the increase in the Reynolds and Weissenberg number, the convergence rate is raised and with the decrease in the viscosity ratio, the convergence rate is improved.

4- Conclusions

The achieved results illustrate that using the binary time algorithm in the preconditioning power sensor method of local stress for solving unsteady viscoelastic flow at a low viscosity rate of 0.5, in spite of the oscillatory feature of the velocity field, in addition to the increment in convergence and reduction in the calculation time, it can increase the stability of calculation. Also, by increasing the Reynolds number and Weissenberg number in the viscosity ratio less than 0.5, it increases the convergence rate of the preconditioning method of the power of the local stress sensor.

References

[1] E. Turkel, Preconditioned methods for solving the incompressible and low speed compressible equations, Journal of computational physics, 72(2) (1987) 277-298.
[2] V. Esfahanian, P. Akbarzadeh, K. Hejranfar, An improved

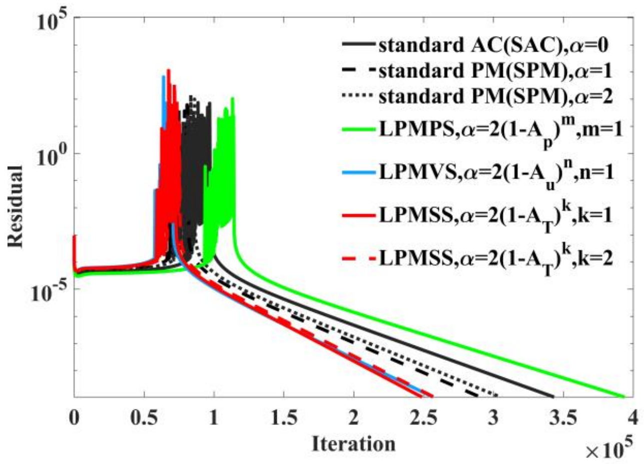

Fig. 2. Effect of the locally power-law PM on convergence rate for unsteady flow of viscoelastic fluid passing between tow fixed parallel plates with $\mathrm{Re}=10$ **,** $\mathrm{Wi}=1$ **and** $\beta=0.25$ **.**

progressive preconditioning method for steady non-cavitating and sheet-cavitating flows, International Journal for Numerical Methods in Fluids, 68(2) (2012) 210-232.

[3] P. Akbarzadeh, S.M. Derazgisoo, A dual-time implicit power-law preconditioning method for solving unsteady incompressible flows, Modares Mechanical Engineering, 16(2) (2016) 99-110.

[4] G. Mompean, M. Deville, Unsteady finite volume simulation of Oldroyd-B fluid through a three-dimensional planar contraction, Journal of Non-Newtonian Fluid Mechanics, 72(2-3) (1997) 253-279.

[5] H. Vosoughifar, Computational Fluid Dynamic in Matlab, Islamic Azad University-South Tehran Branch, (2016).

[6] F. Rouzbahani, K. Hejranfar, Numerical simulation of wave-floating bodies interaction using a truly incompressible SPH method with artificial compressibility approach, Journal of Solid and Fluid Mechanics, 8(1) (2018) 241-252.

[7] S. Aristov, D. Knyazev, Viscous fluid flow between moving parallel plates, Fluid Dynamics, 47(4) (2012) 476-482.

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