Genetic Programming Approach for Flow of Steady State Fluid Between Two Eccentric Spheres

Mostafa Y. El-Bakry[1*] and Amr Radi[2]

[1] Physics Department, Faculty of Education, Girls Colleges, Tabuk, P.O. Box 796, Kingdom of Saudi Arabia
[2] Physics Department, Faculty of Science, Ain Shams University, Abbassia, Cairo, Egypt

* Email: elbakre1987@hotmail.com
Fax: x.966.4422.22285

Received: 26.11.2006, Final version: 16.5.2007

Abstract:
Genetic Programming (GP) is used to estimate the functions that describe the torque and the force acting on the external sphere due to steady state motion of viscoelastic fluid between two eccentric spheres. The GP has been running based on experimental data of the torque at different eccentricities to produce torque for each target eccentricity. The angular velocity of the inner sphere and the eccentricity of the two spheres have been used as input variables to find the discovered functions. The experimental, calculated and predicted torque and forces are compared. The discovered function shows a good match to the experimental data. We find that the GP technique is a good new mechanism of determination of the force and torque of fluid in eccentric sphere model.

Zusammenfassung:
Genetische Programmierung (GP) wird verwendet, um die Funktionen abzuschätzen, die das Drehmoment und die Kraft beschreiben, die auf eine externe Kugel aufgrund der stationären Bewegung eines viskoelastischen Fluids zwischen zwei exzentrischen Kugeln wirken. GP wurde basierend auf experimentellen Daten für das Drehmoment bei verschiedenen Exzentrizitäten angewandt, um ein Drehmoment für jede Zielexzentrizität zu erzeugen. Die Drehgeschwindigkeit der inneren Kugel und die Exzentrizität der beiden Kugeln wurden als Eingabevariablen verwendet, um die gesuchten Funktionen zu finden. Die experimentellen, berechneten und vorhergesagten Drehmomente und Kräfte werden verglichen. Die gefundenen Funktionen zeigten eine gute Übereinstimmung mit den experimentellen Daten. Wir stellen fest, dass die GP-Technik einen neuen guten Mechanismus darstellt, die Kraft und das Drehmoment auf eine Flüssigkeit in einem exzentrischen Kugel-Modell zu bestimmen.

Résumé:
La programmation génétique (GP) a été utilisée pour estimer les fonctions qui décrivent le couple et la force agissants sur la sphère externe et résultants du mouvement en régime établi d'un fluide viscoélastique emprisonné entre deux sphères excentriques. La GP a fonctionné en prenant pour base des données expérimentales du couple pour des excentricités différentes, afin de fournir un couple pour chaque excentricité souhaitée. La vitesse angulaire de la sphère interne et l'excentricité des deux sphères ont été utilisées comme variables d'entrée pour fournir les fonctions. Les forces et les couples expérimentaux sont comparés aux couples et forces calculés et prédits. Les fonctions ainsi découvertes montrent un bon accord avec les données expérimentales. Nous concluons que la technique de GP est une nouvelle méthode satisfaisante pour déterminer la force et le couple exercés par un fluide dans un modèle de sphère excentrique.

Key words: Genetic Programming, eccentric spheres, steady state motion, viscoelastic fluid

1 INTRODUCTION

The information about the mechanical properties of solutions and melts is important for the processing of these materials in almost all branches of industries. Theoretical and experimental studies concerning the flow of viscous or viscoelastic fluids through different bodies have been discussed in [1 - 4]. In general, the solution of the specific boundary value problem based on microscopic models [5, 6] or phemenological state equations of state [7] renders a small number of experimental measurements sufficient to determine a specific set of material parameters. The theoretical and experimental studies con-

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

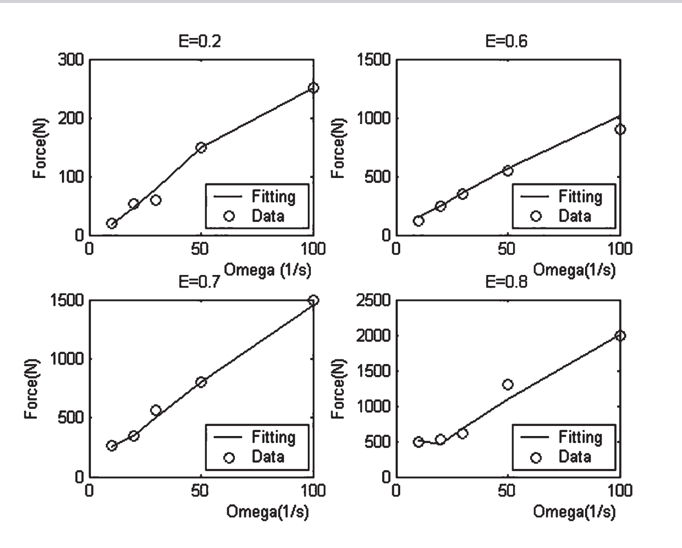

Figure 4 (left): Comparison between the forces calculated by employing our discovered function given in Eq. 3 and the corresponding experimental points of eccentricities of 0.2, 0.6, 0.7, and 0.8.

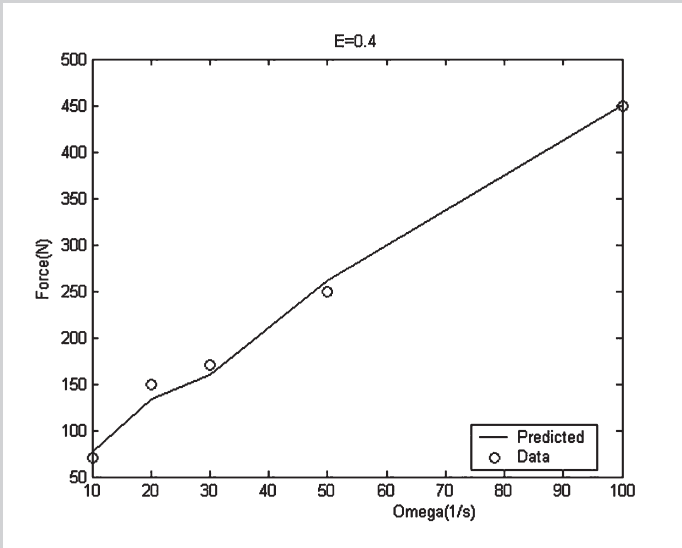

Figure 5: Comparison between the experimental and predicted forces versus angular velocity, Ω, at eccentricity 0.4.

for element *j*. The running process stops when the error *E* is reduced to an acceptable level (0.00001). The training data set which is used based on experimental data for the torque and force with the angular velocity at different eccentricities [18]. GP was run for 800 generations with a maximum population size of 1000. The operators (and selection probability) were: crossover with probability 0.9 and mutation with probability 0.01.

The function set is {+,-, *, \}, and the terminal set is {random constant from 0 to 10, the angular velocity, the eccentricity}. The "full" initialization method was used with an initial maximum depth of 27, and tournament selection with a tournament size of 8. The GP was run until the fitness function is reduced to an acceptable level (0.00001); once for each eccentricity. The discovered function has been tested to associate the input patterns to the target output patterns using the error function. The final discovered function for describing the torque, Δ, at the outer stationary sphere of the eccentric sphere model is given by

$$T = 315.63275 + \Omega + \frac{3118.77485}{E} - \frac{0.76705\Omega}{E} + \frac{\Omega}{E}\left(10 - \frac{E(E-10)}{0.36735}\right) \quad (2)$$

where Ω is the angular velocity of the inner sphere and E is the eccentricity of the two spheres. The final discovered function for describing the force, F_z, at the outer stationary sphere of the eccentric sphere model is given by

$$F_z = 52.018136 + \frac{(98.2873 + 19\Omega - 3.1738E)}{0.45285 - 10\Omega} - 183.017\Omega^2 - 1000\frac{\Omega^2}{E} - 5.710\frac{\Omega}{E} + 10\Omega^2\left(\Omega + 1 + \frac{\Omega}{E}\right)\left(1.82017E + 2\frac{E}{A}\right) \quad (3)$$

where

$$A = 4.9787 + 6.1191\Omega - \frac{2\Omega + 1.55825E}{\Omega - E} - \frac{10\Omega E}{2.3374 - \Omega}$$

3 RESULTS AND CONCLUSION

Our discovered torque function (Eq. 2) and force function (Eq. 3) were tested using the experimental data of the torque and force using 0.3 polyacrylamide in 50/50 glycerin/water. The training data is based on experimental observations at angular velocities ranging from 10 to 100 s^{-1} [18]. The values of the eccentricities of two spheres are taken as 0, 0.2, 0.6 and 0.8 for the torque and for the force the eccentricities are, 0.2, 0.6, 0.7 and 0.8.

Figure 2 displays a good match between the experimental data of the torque at the external stationary sphere using 0.3 polyacrylamide in 50/50 glycerin/water and the calculated ones by employing Eq. 2. After convergence, the discovered function has been used to predict torque with eccentricity 0.4, at angular velocities ranging from 10 to 100 s^{-1} which corresponds to the available experimental data [18] and Figure 3 illustrates the predicted torque compared with experimental data.

Figure 4 displays also a good match between the experimental data of the force at the external stationary sphere using 0.3 polyacrylamide in 50/50 glycerin/water and the calculated ones by employing Eq. 3. After convergence, the discovered function has been used to predict force with eccentricity 0.4, at angular velocities ranging from 10 to 100 s^{-1} which corresponds to the available experimental data [18] and Figure 5 illustrates the predicted force compared with experimental data.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

Finally, we conclude that GP has become a relevant research area in the field of fluid mechanics. The present work presents a new technique for modelling the torque and force of the eccentric sphere model based on GP technique. The discovered function shows a good match to the experimental data for both the torque and the force. We find also that the GP technique is able to improve upon more traditional methods in different branches of physics as discussed in see e.g. [23,24,25].

REFERENCES

[1] Peysson Y, Aubry T, Moan M: Phenomenological approach of the effective viscosity of hard sphere suspensions in shear-thinning media, Appl. Rheol. 16 (2006) 145-151.

[2] Koenigsberg W, Selverian JH: Zone method for representing relaxation characteristics of viscoelastic materials, Appl. Rheol. 15 (2005) 160-171.

[3] Anderson PD, Dooly J, Meijer HEH: Viscoelastic effects In multilayer polymer extrusion , Appl.Rheol. 16 (2006) 198-205.

[4] Edwin CC, Montgomery TS: Creeping Sphere-plane squeeze flow to determine the zero shear rate viscosity of HDPE melts, Appl. Rheol. 14 (2004) 33-39.

[5] Bird RB, Armstrong RC, Hassager O, Curtiss CF: Dynamics of polymeric liquids, Vol. I: Fluid mechanics, Wiley, New York ed.,(1987) and Vol. II Kinetic theory, Wiley (1987).

[6] Giesekus HW, Kroner E, Kirchasner K: Trends in application of pure mathematics to mechanics, Lecture notes in physics 244, Springer, Berlin (1986) 331-348.

[7] Truesdell C, Noll W: Encyclopedia of physics, Vol. III/3: The Non linear field theories of mechanics, Springer, Berlin, Heidelberg, New York (1965).

[8] Wimmer M: Experiments on viscous flow between two rotating concentric spheres, J. Fluid Mech. 78 (1976) 317.

[9] Yamajuchi H, Fujiyoshi J, Matsui H: Viscoelastic fluid in spherical Couette flow, Part I. Experimental study for the inner sphere rotation, J. Non-Newtonian Fluid Mech. 69 (1997) 29.

[10] Yamajuchi H, Matsui H: Viscoelastic fluid in spherical Couette flow, Part II. Numerical study for the inner sphere rotation, J. Non-Newtonian Fluid Mech. 69 (1997) 47.

[11] Yamajuchi H, Nishiguchi B: Spherical Couette flow of a viscoelastic fluid, Part III. A study of outer sphere rotation, J. Non-Newtonian Fluid Mech. 84 (1999) 45.

[12] Jeffery GB: On the steady rotation of a solid of revolution in a viscous fluid, Proc. London Math. Soc. 14 (1915) 327.

[13] Stimson M, Jeffery GB: The motion of two spheres in a viscous fluid, Proc. Royal Soc. A 3 (1926) 110

[14] Majumdar,SR: On the slow motion of viscous liquid in space between two eccentric spheres, J. Phys. Soc. Japan 26 (1969) 827.

[15] Munson BR: Viscous incompressible flow between eccentric coaxially rotating spheres, Phys. Fluids 17 (1974) 528.

[16] Menguturk M, Munson BR: Experimental results for low reynolds number flow between eccentric rotating spheres, Phys. Fluids, 18 (1975) 28.

[17] Abu-El Hasan A, Abdel Wahab M, El-Bakry YM, Zidan M: flow of fluids of grade two between two eccentric rotating spheres, ZAMP 47 (1996) 313.

[18] El-Bakry YM: Theoretical investigation as basis for a new rheometer which measure the Non linear mechanical properties of polymeric solutions or melts, Ph.D. thesis, Faculty of Science, Benha, Egypt (1999).

[19] Banzhaf W, Nordin P, Keller R, Francone F: Genetic programming - An introduction: On the automatic evolution of computer programs and its applications, Morgan Kaufmann Publishers, San Francisco (1998).

[20] Riolo R: Genetic Programming - Theory and Practice, Bill Worzel – Computers, Springer (2003).

[21] El-Bakry MY, Radi A: Genetic programming for hadronic interactions at high energies, Int. J. Mod. Phys. C. 18 (2007) 1-6.

[22] Poli R: Genetic programming for feature detection and image segmentation, School of Computer Science, University of Birmingham (1995).

[23] Kwan CK., Kauppila WE, Lukaszew RA, Parikh SP, Stein TS, Wan YJ, Dababneh MS: Total cross-section measurements for positrons and electrons scattered by sodium and potassium atoms, Phys. Rev. A 44 (1991) 1620.

[24] Parikh SP., Kauppila WE, Kwan CK, Lukaszew RA, Przybyla D, Stein TS, Zhou S: Toward measurements of total cross sections for positrons and electrons scattered by potassium and rubidium atoms, Phys. Rev. A 47 (1993) 1535.

[25] Baluja KL, Jain A: Positron scattering from rare gases (He, Ne, Ar, Kr, Xe, and Rn): Total cross sections at intermediate and high energies, Phys. Rev. A 46 (1992) 1279.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org