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Study on Design of Micro-stirrer for Thrombus Dissolution.

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Introduction

The cerebral thrombus or blood clot might cause cerebral stroke and even decease if the clot could not be dissolved within several hours after it was formed [1]. There were some attempts on the treatment of this illness, for example, using an ultrasonic catheter device to stimulate the thrombus for a quick recanalization [2].

In consideration as mentioned above, a fundamental study[3] has been done experimentally on how to measure the solubility where the clot is under stirring. Thereby, the stirring effect can be easily evaluated by measuring the electrical impedance change of the piezo-patched stirrer. However, there was no detail discussion on structure design of the stirrer. Since dissolution of the blood clot should be speed up, high effective performance in stirring is required. To design a high performance micro stirrer, the fluid-solid interaction analysis is introduced and some structure design ideas are proposed in this study. In the experiment, it is difficult to observe the motion of the stirrer and the flow of the liquid around the stirrer. Therefore, numeric simulation by FEM analysis is applied for evaluation of the performance of the stirrer. Furthermore, several new type of structures of stirrers for the fast dissolution are demonstrated.

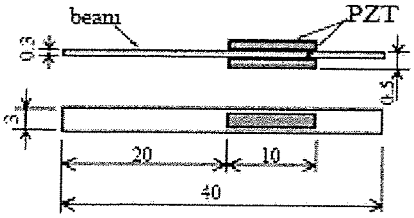

Fig. 1 Schematic of micro stirrer

Fluid-Solid Interaction Analysis

In this section, the fluid-solid interaction analysis is described for design of stirrers, and the performances of stirrers are demonstrated. It is hard to reveal the stirring phenomenon experimentally because of limited measurement instrument.

Therefore, numerical simulation with the fluid-solid interaction analysis is introduced. Figure 1 shows the schematic of a fundamental micro stirrer in analysis by ANSYS. The stirrer is made of a slight beam embedded with a pair of piezocells.

Figure 2 demonstrates the simulation results of the vibration modes of the stirrer in the liquid, and the flow velocity induced in the vessel.

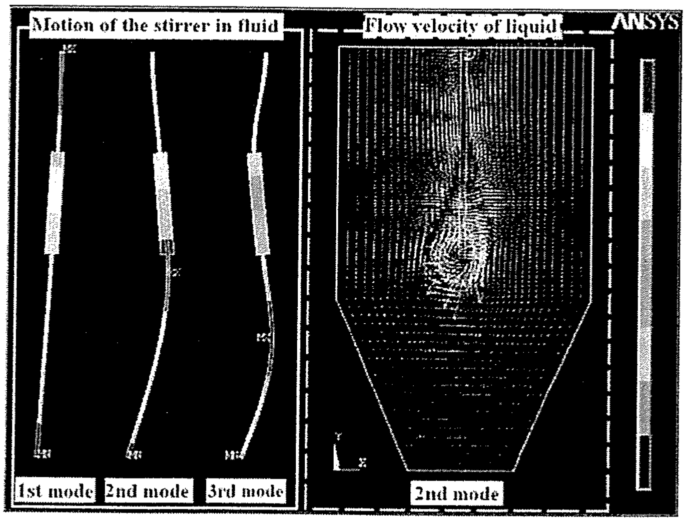

Fig. 2 Result of FSI analysis

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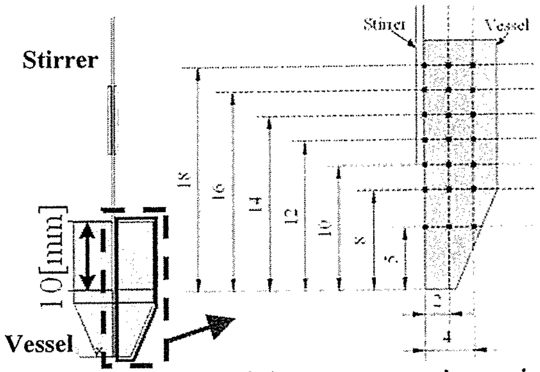


Fig. 3. The position of the representative points

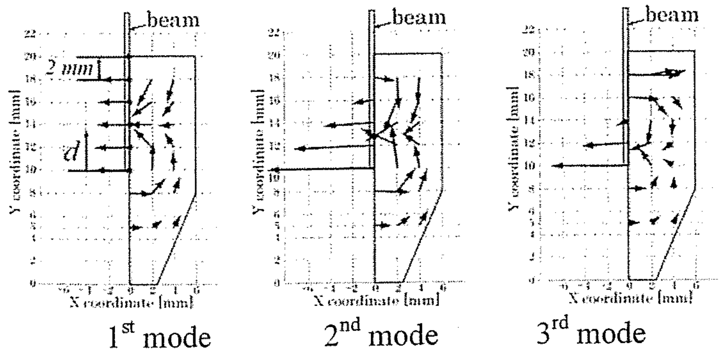
The stirrer is induced by the pair of piezocells and their vibration modes can be easily controlled by the input voltage frequencies. The stirrer is inserted into the liquid in the vessel. The inserting depth from the liquid surface is set at 10[mm].

To evaluate the motion of the liquid when the stirrer is working, 21 representative points are selected for the demonstration of the flow in the vessel as shown in Fig. 3.

Figure 4 shows the flow velocity at the representative points when the stirrer is derived at 1st mode to 3rd mode respectively. The vectors in these figures are the maximum values when the vibration is in steady state. For easy understanding, the sizes of vectors are normalized by the maximum flow velocity in the 2nd mode.

From Fig. 4, it is evident that the flow velocity in the 2nd bending mode is the larger than the other two modes. Therefore, the high solubility is expected from stirring in the 2nd mode.

Now consider the motion of the stirrer. Table 1 lists up the deflections of the stirrer shown in Fig. 4 at every 2[mm] from the tip to the liquid surface. The deflections of the stirrer become small in high modes of vibration.



1st mode 2nd mode 3rd mode

Fig. 4. Flow velocity

Table 1 Deflections of the stirrer at the first three bending modes

d [mm]	Maximum amplitude A_d [m]		
	1st mode	2nd mode	3rd mode
10	9.090E-05	2.350E-05	1.190E-05
8	1.000E-04	7.540E-06	9.530E-06
6	1.090E-04	8.970E-06	5.360E-06
4	1.180E-04	2.650E-05	2.700E-07
2	1.270E-04	4.590E-05	7.250E-06
0	1.360E-04	6.410E-05	1.400E-05

Therefore, we introduce a performance index E_m which is corresponding to the energy per unit mass.

$$E_m = \sum_{d=0}^{5} 2\left(A_{2n,m}\pi\omega_m\right)^2 \qquad (1)$$

where A_{2n} is maximum amplitude at $d=2n$, (n=0,...,5), and the ω_m is frequency at m_{th} mode. Note that the value E_m is at m_{th} mode. Results are shown in Fig. 5.

It shows that the value E_2 at the 2nd bending mode is the largest.

To evaluate the stirring performance of dissolution, an experiment is carried out. Figure 6 shows the experimental setup.

The testing liquid is made by filling glycerol of 0.9[ml] into vessel and then adding red-colored water of 0.9[ml]. In the experiment, the micro stirrer is inserted into the liquid in depth of 10[mm] from the liquid surface.

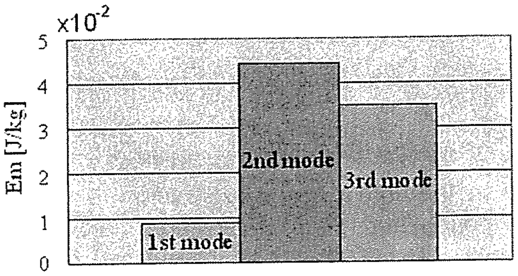


Fig. 5 Energy per unit mass

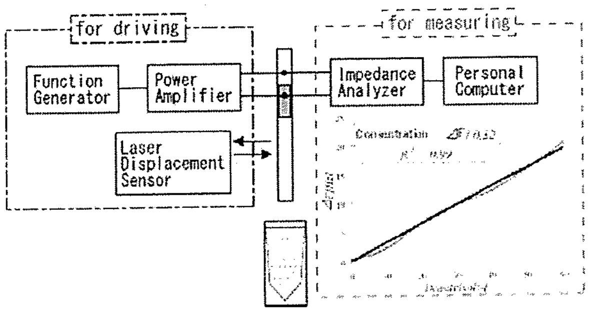


Fig. 6 Experimental setup for dissolution

The input signal for driving the stirrer is formed by a wave function generator (WF1966), and then amplified to 50[V] through the power amplifier (NF4010). The frequencies of the input are set at the resonance frequencies of 1st ~3rd bending mode respectively.

The deflections at the resonance of stirrer are checked by the laser displacement meter (LC-2400). The solubility is estimated by measuring the impedance change in piezocells [3]. As the glycerol is being dissolved the viscosity of the liquid goes higher, and the resonance frequency of the stirrer goes lower. So the solubility can be measured by the change of the resonance frequency, which can be measured by the impedance analyzer (HP4294A).

Further, the solubility can be checked by spread of coloring.

The estimated solubilities at each vibration mode are shown in Fig. 7. It is evident that the 2nd mode has the highest dissolution performance.

Further, comparing of Fig. 7 to Fig. 5, it is clear that the value E_m has the same pattern as the solubility, which indicates the value E_m can be used for estimation of the dissolution performance of the stirrer.

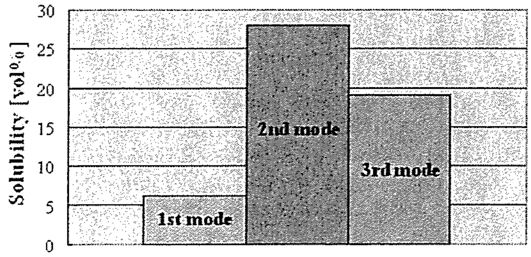


Fig. 7 Experimental results for dissolution

Design of Micro Stirrer

Based on the above analysis, structure design of the stirrer for getting high dissolution is considered. There are many design parameters such as the position for patching PZT, the length of beam, shape of PZT actuator, and so on. In this section, the shape of PZT actuator is taken into account. Figure 8 shows three type shapes of PZT.

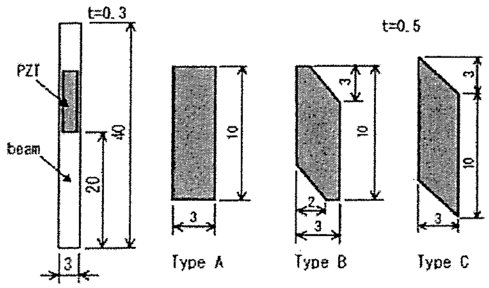


Fig. 8 Model of the new stirrer

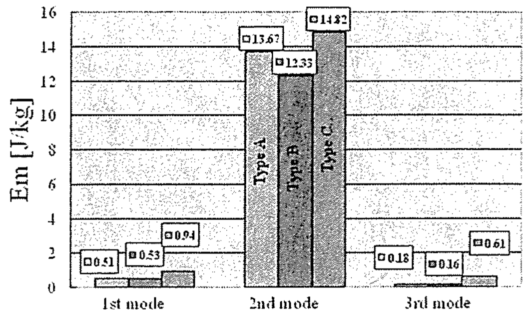


Fig. 9 Energy per unit mass with respect to the new stirrers

Type A is the one discussed in the previous section. Type B is designed for achieving both bending and twisting motion in the stirrer. Type C is the one modified from Type B by extending the corners.

The values E_m described in $Eq.1$ for each types are calculated and plotted in Fig. 9. Figure 9 shows that Type C has higher value E_m comparing with the other shapes of piezocells.

Therefore, it can be concluded that the stirrer of Type C is expected a big effect.

Conclusion

In this paper, numeric simulation by FEM with the fluid-solid interaction analysis was applied for evaluation of the performance of the stirrer. Consequently, the performance index was introduced for designing the high efficiency stirrer. And the shape of PZT actuator was designed based on the performance index.

References

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