SYSTEMATIC SIMULATION COMBINING CFD AND 1-D DRIVE SYSTEM OF HIGH-VISCOSITY FLUID DISPENSING JET IN MICRO-ELECTRONICS PACKAGING

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Adhesives are used extensively in the assembly and packaging of micro-electronics and MEMS, especially in the current mass production of electronic hardware, e.g., computers, cell phones, smart cards, and sensors. They are used both in single-chip packages and multichip assemblies.[1] Adhesives, as a kind of fluid, are used to produce dots, lines, or patterns, and has been dispensed on the substrate. The process is called fluid dispensing. Stencil printing, screen printing, pin transfer, daub transfer, and stamping are examples of mass-transfer types.[1] In comparison, selective dispensing methods are computer data driven, dispensing adhesives where it is necessary. One of the selective dispensing type is contact dispensing, in which the dispensing tools have a short time of contact to the substrate, e.g., syringe-needle dispensing. The other one is jet dispensing, a direct-dispensing process where the adhesive is forced through a fine nozzle and programmed to flow at selected position controlled from a computer database, which is not required to contact the surface. Currently, the selective dispensing used in very large portion of all production processes. As a sketch, Figure 1 shows the basic components of a pneumatic-driven jet dispensing pump. The compressed air pushes the piston up, when the pneumatic valve is triggered. the adhesive is pressurized to fill the void left when the piston retracts from the seat. When the pneumatic valve is closed, the spring-driven ball returns, the force pushes the fluid through the nozzle. Once the ball impacts on the seat, it breaks the stream of adhesive, which is then jetted in precisely controlled amounts onto the substrate.

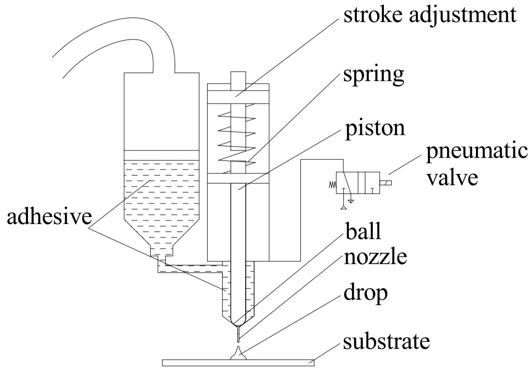

Figure 1: Sketch of a pneumatic-driven jet dispensing pump

This is a kind of drop-on-demand (DOD). The differences to DOD inkjet includes: relatively high viscosity fluids, relatively large nozzle size, and mechanical-driven in jet dispensing.
Currently, many reserachers build one-dimensional model to analyze the perfomance of whole system[2, 3, 4, 5], in which the nozzle part is simplified as a 1-D nozzle; While others build detailed model of ball-seat mechanism[6, 7, 8], in which the ball velocity is pre-determined. Both need improvements. The 1-D models need ball-seat mechanism detailed data, such as pressure, flow, and considering fluid properties. And the ball-seat mechanism needs accurate drive force and needle (or piston) position. Therefore, Combination of 1-D model of drive system and detailed ball-seat mechanism can help to acquire more accurate analysis.
In this paper, the systematic model combining CFD and 1-D drive system has been built. The CFD model is built in OpenFOAM, and 1-D drive system model is embedded to couple the CFD model. Thus, the ball-seat mechanism and the 1-d drive system is coupled in one application, which can be more easily applied, and extra interface with other simulation tools, such as AMESim, is not necessary.

1 Model

The CFD geometric model of ball-seat mechanism is shown in Figure 2. The ball is moving up and down according to the force calculated with 1-D drive system model as

$$F_{\mathrm{p}} = m_{\mathrm{p}} a_{\mathrm{p}} \tag{1}$$

where, F_p is the total force acting on the piston, m_p is the mass of the piston assembly, and a_p is the acceleration of the piston.

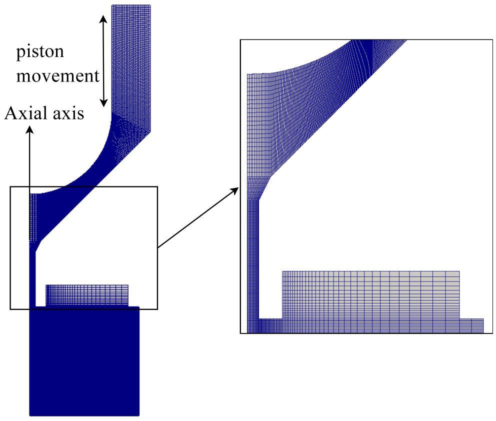

Figure 2: CFD geometric model of ball-seat mechanism

$$F_\mathrm{p} = F_\mathrm{a} + F_\mathrm{s} + F_\mathrm{g} + F_\mathrm{f} + F_\nu \tag{2}$$

$$F_\mathrm{s} = ky + F_\mathrm{d} \tag{3}$$

$$\dot{y} = \int_0^t a_\mathrm{p} dt \tag{4}$$

where, F_a is the force generated by compressed air, F_s is the spring force, F_g is the gravity force, F_f is the friction force acting on the piston, F_ν is the shear force due to fluid flow in the annulus, k is the spring coefficient, F_d is the pre-compressed spring force, y is the displacement of the piston, and t is the time.
The compressed air charges into or releases from the chamber under piston as adiabatic process because of the very short period in several milliseconds. The mass flow rate of air charging and releasing is [9]

$$q'_m = 0.04 \frac{p_{a1}}{\sqrt{T}} S, \ (p_{a2}/p_{a1} \leq b) \tag{5}$$

$$q_m = q'_m \sqrt{1 - \left(\frac{p_{a2}/p_{a1} - b}{1-b}\right)^2}, \ (b < p_{a2}/p_{a1} \leq 1) \tag{6}$$

where, q_m is the mass flow rate of air charging into or releasing from the chamber, T is the temperature of air inside the chamber, S and $b = 0.528$, respectively, are the effective area and the critical pressure ration of the pneumatic valve orifice, p_{a1} and p_{a2} are the pressure at up- and down-streams of the valve orifice.
The laminar fluid system can be described as continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0, \tag{7}$$

momentum equation

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla(\rho \mathbf{U}\mathbf{U}) = -\nabla p - \nabla \cdot \tau, \tag{8}$$

where U is the velocity of fluid, ρ is the density of the fluid, p is the pressure, and τ is the stress.
To track the interface of fluid-air, the two-phase VOF (Volume of Fluid) model is used

$$\rho = \alpha_2 \rho_2 + (1 - \alpha_2)\rho_1 \tag{9}$$

where ρ_2 is the fluid density, α_2 is the fraction of fluid, ρ_1 is the air density.
One adhesive is modelled as a Cross-Power-Law fluid,

$$\eta_1 = \eta_\infty + \frac{\eta_0 - \eta_\infty}{1 + (m\dot{\gamma})^n}, \tag{10}$$

where η_0 and η_∞ are the zero-shear-rate and infinite-shear-rate kinematic viscosity respectively, m is relaxation time, n is the power index.
The other adhesive is modeled as a Newtonian fluid,

$$\eta_2 = \eta_0, \tag{11}$$

Because of the high pressure in the ball-seat chamber, the fluid compressibility is considered. The density can be well approximated by a linear relation,

$$\rho_2 = \rho_{20}(\beta(p - p_0) + 1), \tag{12}$$

where ρ_{20} is the density at the reference pressure p_0, β is the isothermal compressibility of the fluid. The computation procedure is as follows:

1. start;
2. according to force acting on the piston to calculate the piston position and velocity using the 1-D drive model;
3. update the boundary condition;
4. calculate the CFD model;
5. collect the pressure acting on the piston, and the viscous stress;
6. go to step 2 to calculate the piston position of next time step;
7. end.

2 Results

Results will be presented in the workshop.

Acknowledgments

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