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A flash photography method for the measurements of the fluid flow dynamic of a fluid dispensing system

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ABSTRACT

In this paper, we present a flash photography method for the measurements of the fluid flow dynamic of a fluid dispensing system. A fluid dispensing system is one of the key processes to deliver fluid materials to various positions in assembly parts of several manufacturing industries. A dispensing process is a complicated dynamic process and time-dependent. The parameter identification of a fluid dispensing model by using with measurement values of the accumulated final volume is usually employed. This technique may not provide the satisfactory results. To improve the accuracy of the parameter identification, the fluid flow measurements based on the flash photography methods is proposed. The experiments with various fluid levels inside a syringe were carried out to evaluate the performance of the proposed system. The pressure dependent fluid flow rate curve constructed from the measurement values is presented, to identify the parameters associated with the model. The measured parameters are consistent with the fluid properties reported in the literature.

1. Introduction

A fluid dispensing system is one of the major processes in various manufacturing industries such as the surface mount technology (SMT), Additive Manufacturing (AM) technologies and the Hard Disk Drive (HDD) assemblies [1–8]. It is also an essential part of many experiments related to the life science research [9–23]. For such experiments, samples or solutions of protein/DNA have to be efficiently dispensed into microwells or onto substrates since most of bioactive samples are often fragile and expensive. As the micro- or nanoliter level of the dispensing volume becomes increasingly universal in life science research, the requirement for the precise control of a dispensing fluid dot is inevitable. These enormous requirements also arise in electronics manufacturing industries. A fluid dispensing system is usually designed to deliver fluid materials such as epoxy, adhesive, encapsulant to various positions in assembly parts. In SMT processes, a dispensing system is typically used to apply the solder paste onto pads of a printed circuit board (PCB) before performing the reflow soldering process. As the reduction of the pad size/pitch and the demand for the high-reliability electrical interconnection, the amount and the profile of a solder paste formed on the PCB have to be well controlled. The comparable circumstances also occur in HDD assembly industries where a dispensing system is used in many processes. One of the key critical processes is the attachment of recording heads (slider) and supporting structures (suspension) by using a micron-size adhesive dot on the desired position of a suspension. The automatic placement of a slider on top of an adhesive dot is performed before processing in a UV curing system. The amount and profile of the adhesive dot are the critical parameters in the current HDD manufacturing process, since the dramatical reduction in a slider moreover, the suspension geometry.

A time-pressure dispensing is a complicated dynamic process and difficult to control [1,24–31]. The system performance can be affected by many process parameters such as a pressure of a compressed air supply, a fluid temperature, structural parameters of a system and the flow behavior of the fluid being dispensed. The inconsistent amount of the fluid dispensed can be occurred due to the changes in process parameters during the dispensing action. One of the primary parameters causing the problem of the inconsistent dispensing is the fluid level (or air volume) variation inside the syringe. As the more fluid is dispensed out of the syringe, the less pressure is generated inside the syringe. As a result, the less volume of fluid is dispensed. Such variation in the dispensed fluid volume contributes to the serious consequence in the time-pressure dispensing processes, in particular for the process which requires the accurate volume of a dispensed fluid dot [1]. For eliminating such a problem, various control schemes have been proposed to provide the real-time feedback control of dispensing

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processes. The on-line control method requires the information about the actual volume/height or the flow rate of a fluid dot being dispensed in real time. However, such information may be difficult to retrieve in practical dispensing processes. Therefore, the method based on a model to predict the dispensing fluid volume is more preferred in manufacturing processes. The anticipated amount is usually used as a feedback signal for the controller of the dispensing process. There are numerous models developed and evaluated to predict the performance of the dispensing process accurately. The extensive review of the models to predict the performance of time-pressure dispensing models can be found in the literature [1].

Li et al. proposed the model identification method for the estimation of the process parameters and used as the initial values for the adaptive control of the process [24]. Other methods were also used to identify the process parameters [25–27]. However, in practical fluid dispensing systems, they usually have limited computational resources. The processing time and memory of the system have to share with other control units such as an X-Y stage and a vision system. Therefore, complex or elegant models used to predict the fluid dispensing volume may not apply to a practical fluid dispensing hardware. The simple incremental adjustment method proposed by Li et al. involves the control of an opening time of a solenoid valve which supplies the compressed air to a syringe. The opening time is initially calculated by the model calibration at the beginning of a dispensing process. After the process starts, the opening time is then gradually refined as the fluid level changes. Their simulation and experimental results with different fluid heights inside a syringe show the smaller fluid dispensing volume variation than the ones from the conventional controller. However, the accuracy of their method depends profoundly on the results from the model calibration and the integral gain that need to be determined from the experiment. For the calibration of the dispensing system, a 2D vision system is employed in their work for the determination of final volume dispensed. This measurement system may not provide satisfactory results since the final dispensing volume is the accumulated results of the time-dependent fluid flow process. It would be more desirable if the parameters of the model calibration can be determined directly from the fluid flow rate-pressure relationship (Q-Δp) of a generalized power law fluid equation. Therefore the fluid flow measurements based on the flash photography methods is proposed in this paper. The proposed method significantly improves the calibration procedure so that the parameters can readily be determined directly from a simple measurement arrangement.

2. Modeling of a fluid dispensing process

A liquid dispensing process model has been studied by many researchers [1,24–27] (Fig. 1). The key issues are to characterize and represent the flow behavior of the fluid being dispensed. Under the assumption of the fluid of non-Newtonian flow behavior as the most of the fluid used in various manufacturing process, the relationship between the shear stress and the shear rate in the fluid is typically non-linear. Among these models, the generalized power law is the most accepted. The relationship of the fluid flow rate Q and the pressure in one dispensing cycle Δp can be expressed by [24]:

$$Q(V_f) = K_1(V_f)\Delta p^{N(V_f)} + K_2(V_f)\Delta p^{N(V_f)-1} + K_3(V_f)\Delta p^{N(V_f)-2} \tag{1}$$

where V_f is the fluid volume inside a syringe, $N(V_f) = 1/n(V_f)$ and the coefficients $K_1(V_f), K_2(V_f), K_3(V_f)$ are

$$K_1(V_f) = \frac{2L(V_f)\pi n R^2 C^{1+(1/n)}}{k^{1/n}(3n+1)} \tag{2}$$

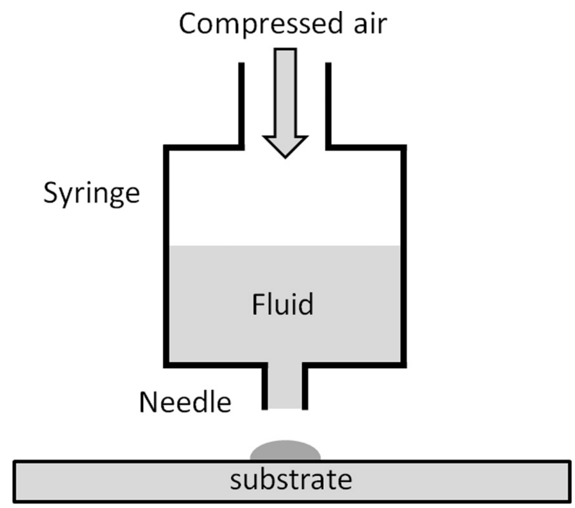

Fig. 1. A diagram of a typical fluid dispensing system.

$$K_2(V_f) = \frac{8L(V_f)^2 \pi n^2 R \tau_0 C^{1+(1/n)}}{k^{1/n}(2n+1)(3n+1)} \tag{3}$$

$$K_3(V_f) = \frac{16L(V_f)^3 \pi n^3 R \tau_0^2 C^{1+(1/n)}}{k^{1/n}(n+1)(2n+1)(3n+1)} \tag{4}$$

and $C = (R - r_0(V_f))/2L(V_f)$, τ_0 is yield stress of liquid, $L(V_f)$ is the length of the fluid inside a syringe, R is the radius of a syringe k is the viscosity of the fluid, n is the power law index and the critical diameter $r_0 = 2\tau_0 L(V_f)/\Delta p$. In the next section, the results from the experiment will confirm that the parameters $N(V_f), K_1(V_f), K_2(V_f), K_3(V_f)$ are dependent on the fluid level inside a syringe.

Since the pressure $\Delta p(t)$ is the function of time, therefore the volume dispensed under such pressure in one operating cycle can be calculated using the time integration as:

$$\hat{V}(T, V_f) = K_1(V_f)\int_0^T \Delta p(t)^{N(V_f)} dt + K_2(V_f)\int_0^T \Delta p(t)^{N(V_f)-1} dt + K_3(V_f)\int_0^T \Delta p(t)^{N(V_f)-2} dt \tag{5}$$

where $\hat{V}(T, V_f)$ is the estimated dispensing amount at a time T. By using the estimated dispensing amount calculated by Eq. (5), the opening time of a solenoid valve supplying the compressed air to the syringe can be effectively fine-tuned as the fluid level gradually changes as shown in [24].

3. Experimental setup

The diagram in Fig. 2a shows the experimental setup. These include the fluid dispensing system and the flash photography system. The fluid dispensing system consists of a voltage-controlled pressure regulator (SMC), a transmission line and a dispenser containing a syringe and a needle. For monitoring a pressure inside the syringe, a high precision pressure transducers (SMC) is connected to the special design connector mounted on the dispensing needle. The magnitude and duration of the pressurized air are controlled by using a voltage-controlled regulator. The desired values of magnitude and duration of the pressurized air are configured using the signal generator (Agilent) in which the output signal is sent to the regulator. Therefore, the amount of fluid dispensed can be regulated. The signals from the signal generator are also used for the