Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Cite this as: Yan-xiang Yang, Bing-qian Tan, Chang-wen Liu, Ping Zhang, Qi-jiang Le, Ben-xi Zhang, 2019. A T3 metering theory used for diesel exhaust fluid dosing and failure diagnosis in selective catalyst reduction dosing systems. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 20(5):334-346.
https://doi.org/10.1631/jzus.A1800518

A T3 metering theory used for diesel exhaust fluid dosing and failure diagnosis in selective catalyst reduction dosing systems

Key words:
DEF dosing unit, Plunger-sleeve pump, T3 metering theory, Sensor-free diagnosis

To meet strict emission regulations, SCR is essential for diesel engines.

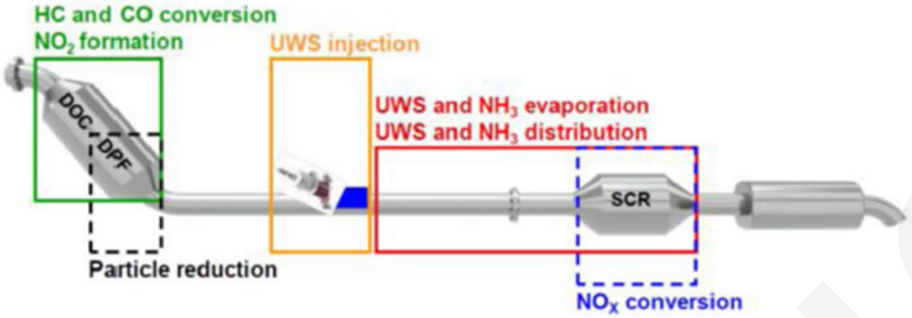

Fig. 1

Based on the mechanical structure and combustion organization method of existing diesel engines, with some after-treatment processes, such as EGR (exhaust gas recirculation) and SCR (selective catalytic reduction), the reduction of NOx emissions needed to meet the stricter regulations can be achieved (Grout et al., 2013).

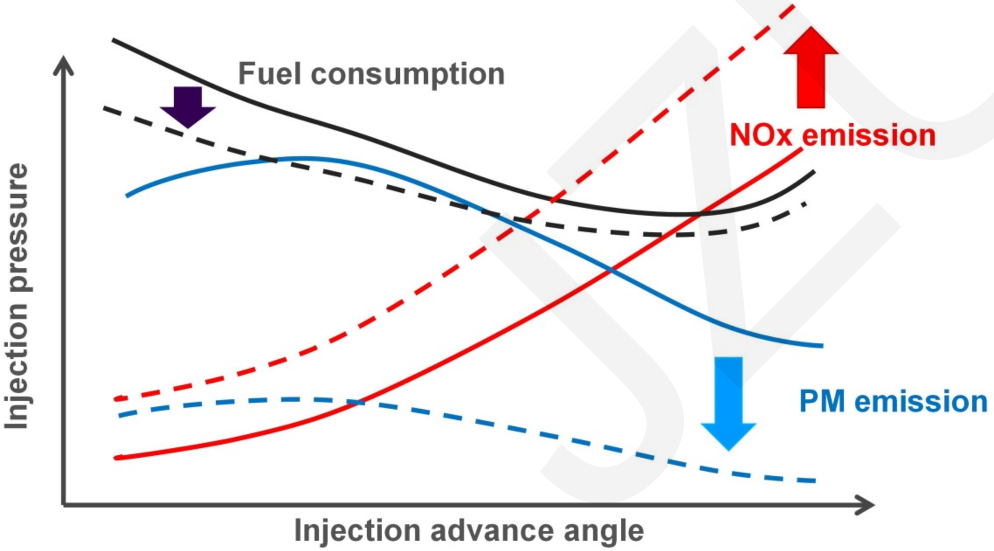

Fig. 2

Fig.2 For diesel engines, large decreases in particulate emissions and fuel consumption can be achieved by using the trade-off curve feature (Lambert et al., 2004; Norbert et al., 2011; Scarnegie et al., 2003; Cloudt et al., 2009), while increased NO_x emissions can be eliminated with an SCR system.

Dosing pumps for SCR

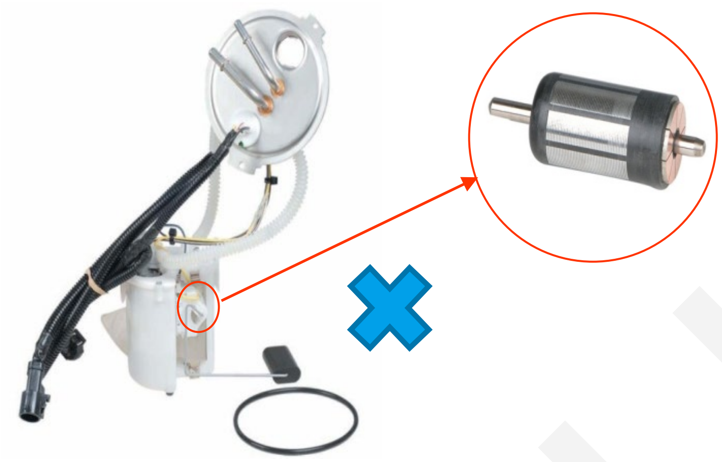
Fig.3 A typical CR pump

CR technology art

SCR DEF is an electric conductive fluid, which can not be delivered with electric rotary pump based on CR technology art.


Fig. 4a Grundfos SCR pump- air-assisted


Fig. 4b Bosch denoxtronic 2.2 pump- airless

Traditional Diaphragm pumps

- Not small enough, with low integration.
- Hard to avoid the problematic freezing and clogging issues inside the supply tube.
- More expensive and less reliable.

Dosing pumps for SCR

Plunger pump and Sleeve pump

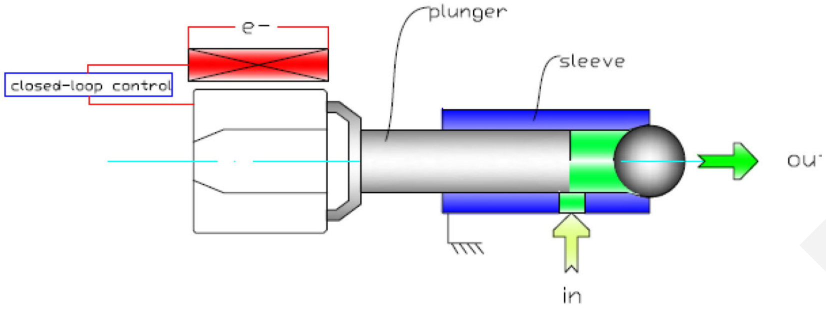

Fig.5 A type of plunger pump

Sleeve pump

- An innovative design of a dosing unit called a sleeve pump, made by FAI in China.
- The liquid is delivered by a type of sleeve with a free armature rather than a plunger motion, and the armature is free of valve.

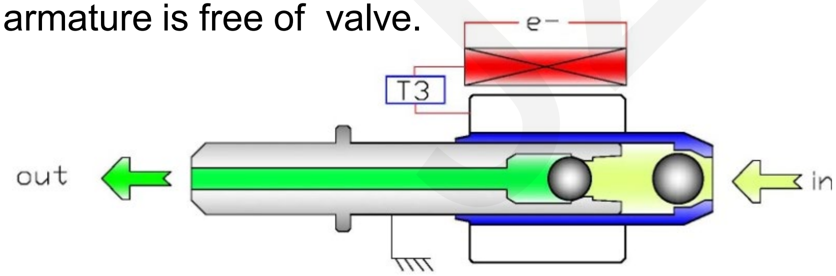

Fig.6 A type of sleeve pump

Plunger pump

- A dosing unit designed for DEF by Delphi (Lee *et al*., 2010; Needham *et al*., 2012)
- It is a linear plunger pump driven by electro-magnetic force from a solenoid coil. This type of plunger pump was invented by Ficht (Heimberg *et al*., 1996) .

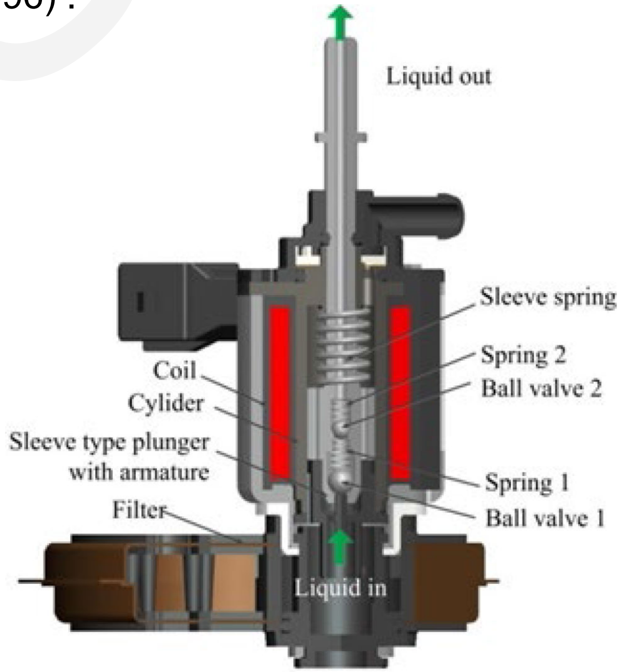

Fig.7 Detailed structure of the sleeve pump

Physical and electrical models of the sleeve pump

Focus on:

1) Current in the coil;
2) Displacement of the armature;
3) Voltage change.

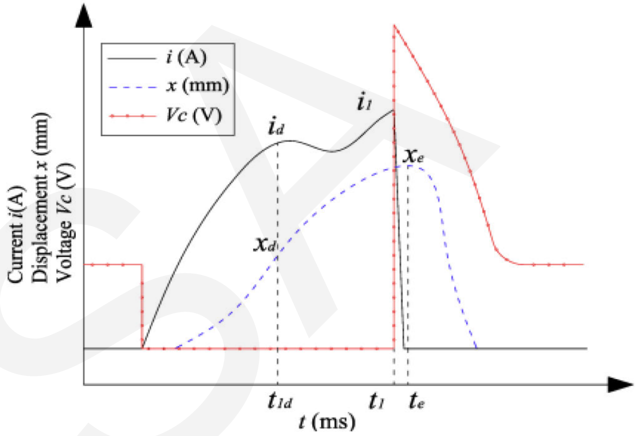

Fig.8 Variation in the current passing through the coil wire in a sleeve pump

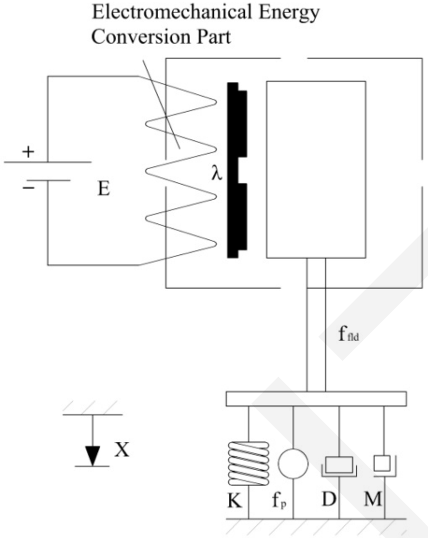

Fig.9 It is difficult in controlling the liquid delivery amount because output of the system is inherently subject to variation due to state changes

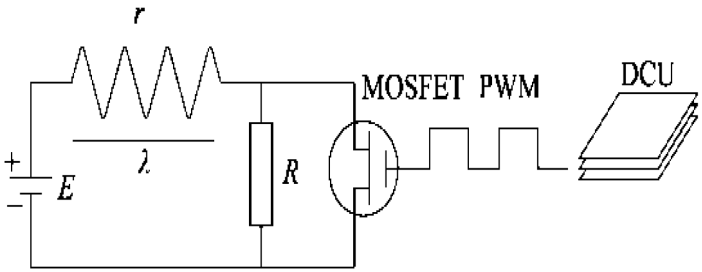

Fig.10 A typical electrical circuit for driving the sleeve pump

Governing equations

Based on the physical and electrical models, we have:

Energy balance equation:

$$\int_0^{t_1}(ei-ri^2)dt=\int_0^{x_e}D(\frac{dx}{dt})dx+\int_0^{x_e}K(x+x_0)dx+\int_{x_d}^{x_e}f_p dx+w_{fld} \qquad (1)$$

Electric equations:

$$\frac{d\lambda}{dt}=e-ir \qquad (t<t_1) \qquad (2)$$

$$\frac{d\lambda}{dt}=e-iR \qquad (t>t_1) \qquad (3)$$

Energy balance equation in dimensionless form:

$$\int_0^{T_1}(EI-\bar{r}I^2)d\tau=\int_0^{X_e}\overline{D}(\frac{dX}{d\tau})dX+\int_0^{X_e}\overline{K}(X+X_0)dX+\int_1^{X_e}F_p dX+W_{fld} \qquad (4)$$

Electric equations in dimensionless forms:

$$\frac{d\Lambda}{d\tau}=E-I\bar{r} \qquad (\tau<T_1) \qquad (5)$$

$$\frac{d\Lambda}{d\tau}=E-I\overline{R} \qquad (\tau>T_1) \qquad (6)$$

Whole-state model of liquid discharge (T3 metering theory)

- Whole-state model of liquid discharge

$$Q^2 + \alpha Q = \beta I_1 \mathrm{T3} \qquad (24)$$

Where

$$\alpha = \frac{6A_p \Pi P_0}{\Omega \eta(Q)} \qquad (25)$$

$$\beta = \frac{6A_p C \Pi^2}{\Omega \eta(Q)^2} \qquad (26)$$

$$\mathrm{T3} = T_3 - T_{3b} \qquad (27)$$

Independent from state

Effects from state

$$T_{3b} = [(I_1 \Lambda_d - \int_0^{\Lambda_1} I d\Lambda) + W_{fld} + \int_0^{X_e} \overline{D}(\frac{dX}{d\tau})dX + \overline{K}X_e(\frac{X_e}{2} + X_0)]/(CI_1) \qquad (28)$$

Experimental verification of T3

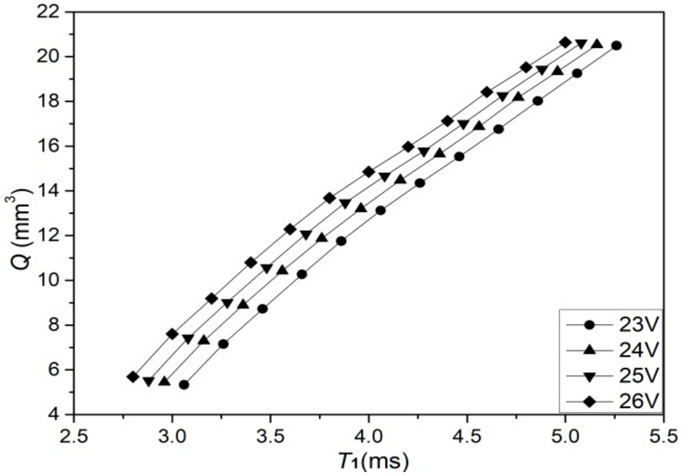

Fig.11 Mass discharge variation caused by changes in the power level

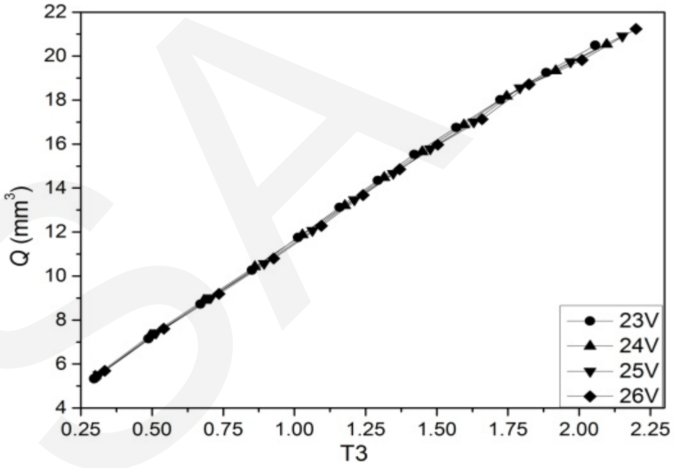

Fig.12 Mass discharge against T3 at different power levels

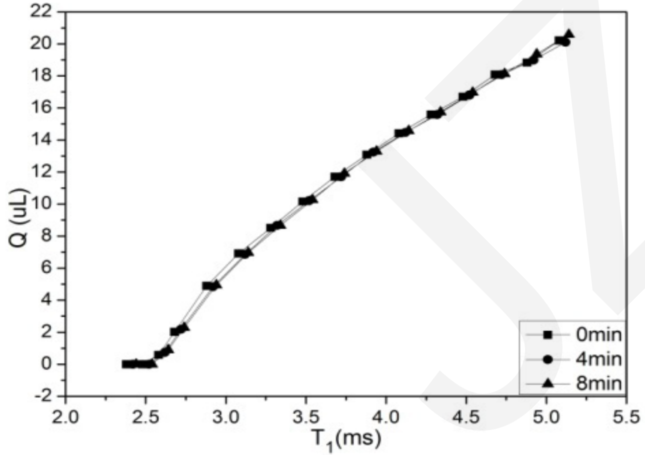

Fig. 13 Mass discharge variation caused by changing temperature

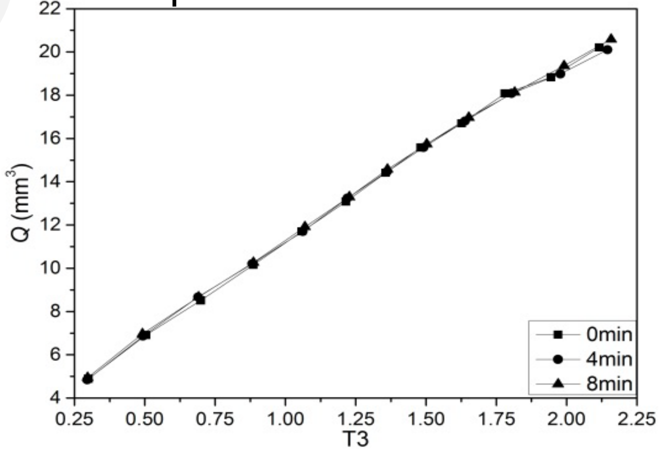

Fig. 14 Mass discharge results using T3 for different temperatures

Application to SCR dosing systems and typical failure modes

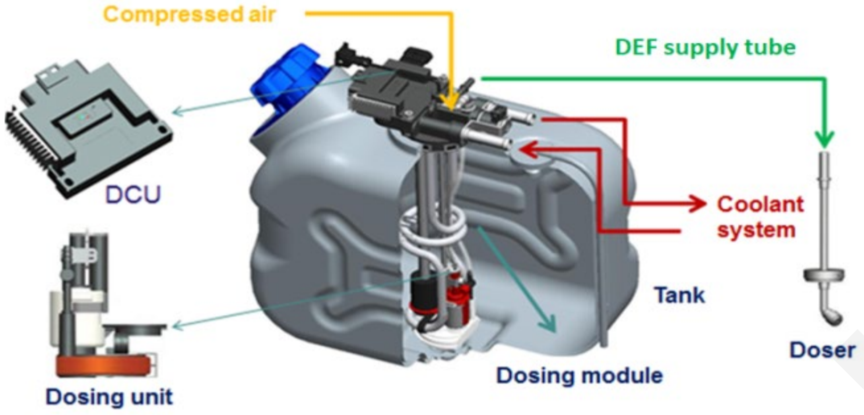

Fig. 15 Application of a sleeve pump type dosing unit to an air-assisted DEF dosing system

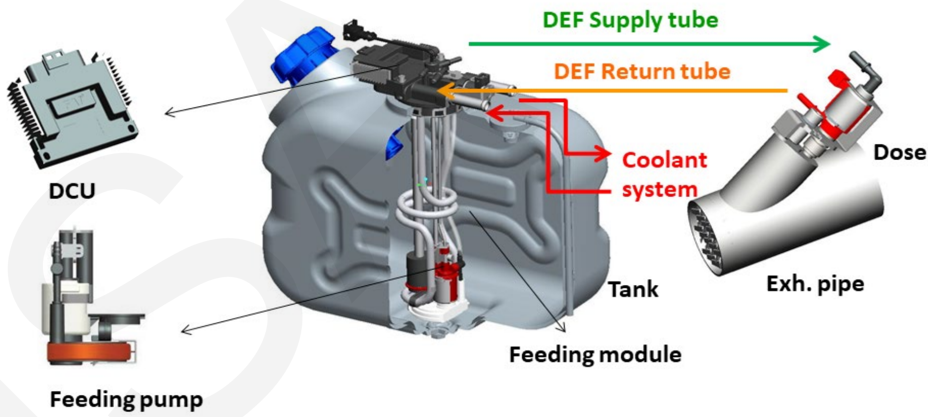

Fig. 16Application of a sleeve pump type dosing unit to an airless DEF dosing system

Table 1 Specific failure modes of air-assisted and airless dosing systems

Item	Type	Performance	Type of dosing system		Traditional detection methods
			Air-assisted	Airless	
A	Electrical failures	Short circuit or break in line, coil or connector	Yes	Yes	By electrical circuit signal test with DCU
B	DEF tube or nozzle blockage	High pressure in the tube or nozzle	Yes	Yes	By pressure sensor
C	Short of compressed air	Low air pressure	Yes	No	By pressure sensor
D	Mechanical failures	Sleeve stuck, lack of liquid in chamber A	Yes	Yes	Emission deterioration test

Parameter T_3 can be flexibly used for typical failure mode detection.

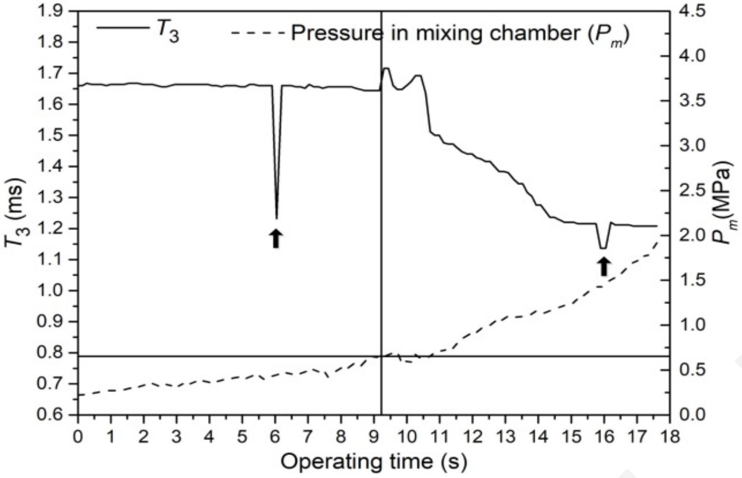

Fig.17 T_3 data record when a nozzle is clogging

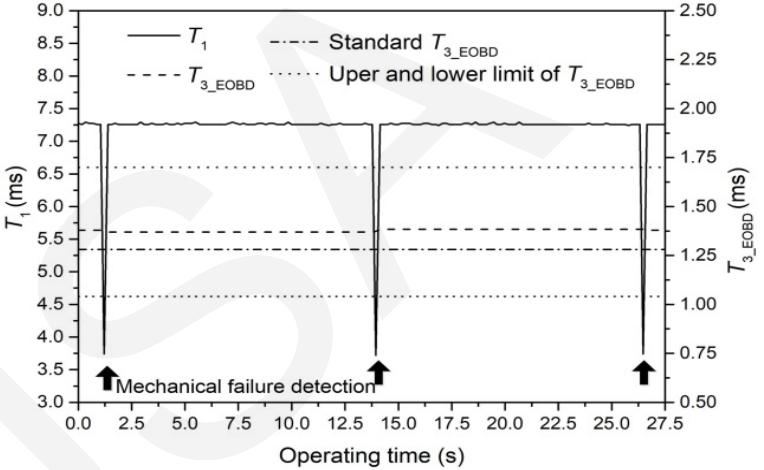

Fig.18 T_{3_EOBD} test for mechanical failure detection

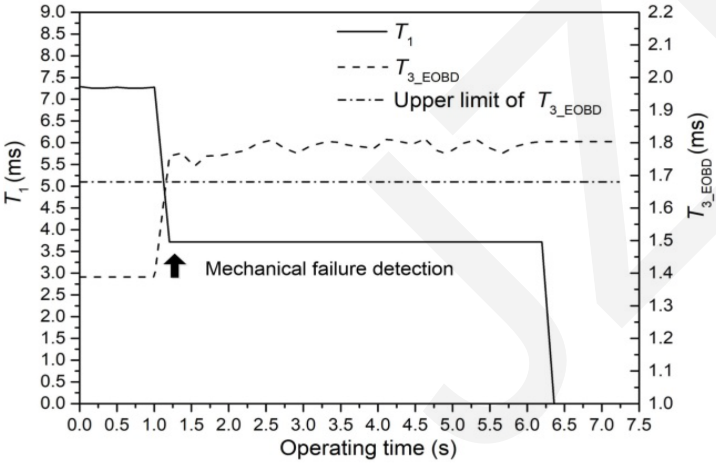

Fig.19 Mechanical failure caused by lack of liquid

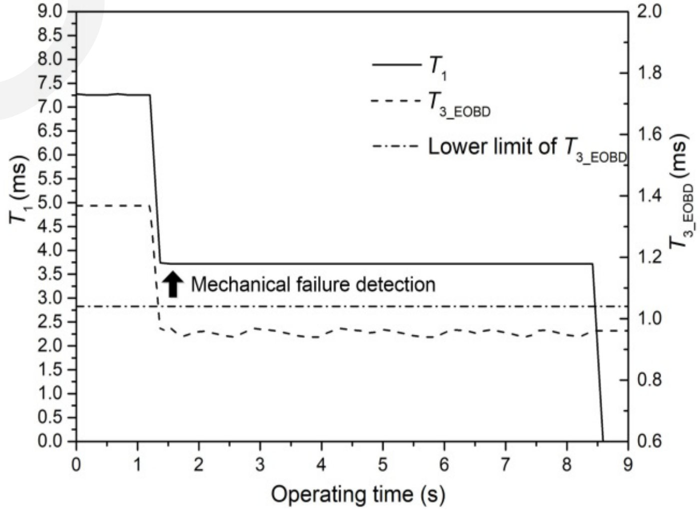

Fig.20 Mechanical failure caused by a stuck plunger