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Effect of in Line Suction Damper Chambers Matrix on the Performance of Vacuum Paper Feeding System

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Abstract:

The synchronization of paper feeding to the offset printing machine drums from feeding pile is carefully design. The suction head is responsible to attract the paper from the pile by the power of vacuum. The vacuum pressure at the suction head should has the strength to hold the paper and at constant rate by the effect of the in line suction damper that reduce the vacuum pump pressure pulsation. In this paper, an unsteady mathematical model for the in line suction damper has been developed. A series of in line suction dampers with constant volume and different chamber matrix construction has been introduced. The effect of in line suction damper chambers matrix on the dynamic performance of rough vacuum system has been studied at different inlet vacuum pressure oscillations. Up to our knowledge there is no analytical model to explicitly characterize this phenomenon. The unsteady paper pickup force produced from different damper construction is introduced. It has been concluded that both flow path of 9 chamber design are the more useful design than the rest of damper design and is a good choice as an inline suction line vacuum damper in the paper feeding mechanism of printing machine.

Key words:

Paper feeding, suction damper, vacuum pressure, rough vacuum system.

Nomenclature

A_h	Suction cup hole area (m^2)
G_k	Represents the generation of turbulence kinetic energy due to themean velocity gradients
G_b	The generation of turbulence kinetic energy due to buoyancy, calculated as described in Section
k	Boltzmann constant ($mbar \cdot l \cdot K^{-1}$)
M	Molar mass ($g \cdot mol^{-1}$)
m_p	Paper mass (kg)
m_T	Particle mass (g)
n	Number of suction cup in feeding mechanism.
N_A	Avogadro constant (mol^{-1})
p	Gas pressure (mbar)
R	Molar gas constant ($mbar \cdot l \cdot mol^{-1} K^{-1}$)
p_{atm}	Atmospheric pressure (bar)
p_v	Vacuum pressure (bar)
p_{vA}	Pressure amplitude (mbar)
P_{vo}	Initial pressure (mbar)
S_k, S_ε	User-defined source terms
t	Time (s)
Y_M	Represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate
α_k	Inverse effective Prandtl numbers for k
α_ε	Inverse effective Prandtl numbers ε.
θ_p	Paper feeding angle (deg)
ω	Frequency (s^{-1})

1. Introduction

Modern offset printing machines and paper folding machines require high dynamic performance for paper feeding to achieve the precise printing job. Vacuum systems can be found in printing industry on sheet-fed presses, vacuum frames in plate-making, feeding system of folding and binding machine…etc. In prepress; for offset printing, the film assembly is put on the plate, and both are set in the copying frame of the plate-making for the purposes of photographic image transmission onto an offset plate in a contact method. Both film and plate are exposed in an exposure frame using vacuum air to ensure the complete adhering of the film with the plate in order to have a correct process. The idea of sheet feeding is the same in almost all feeding systems in the printing industry including the printing and folding machines. The task of the feeding system is to pick up the sheets from the feed pile, to separate the first sheet from the rest of sheets, to convey the separated sheet to the feed table via a feed system, and to align the sheets at the feed guides as shown in Figure (1).To attract the paper the under pressure has to have the strength to pick up the paper. The suction head has been controlled by rotating valve controls that supply vacuum to the suction head cups. When the air control function is enabled at the control console, the pickup suckers automatically descend onto the pile and lift the first sheet [6].

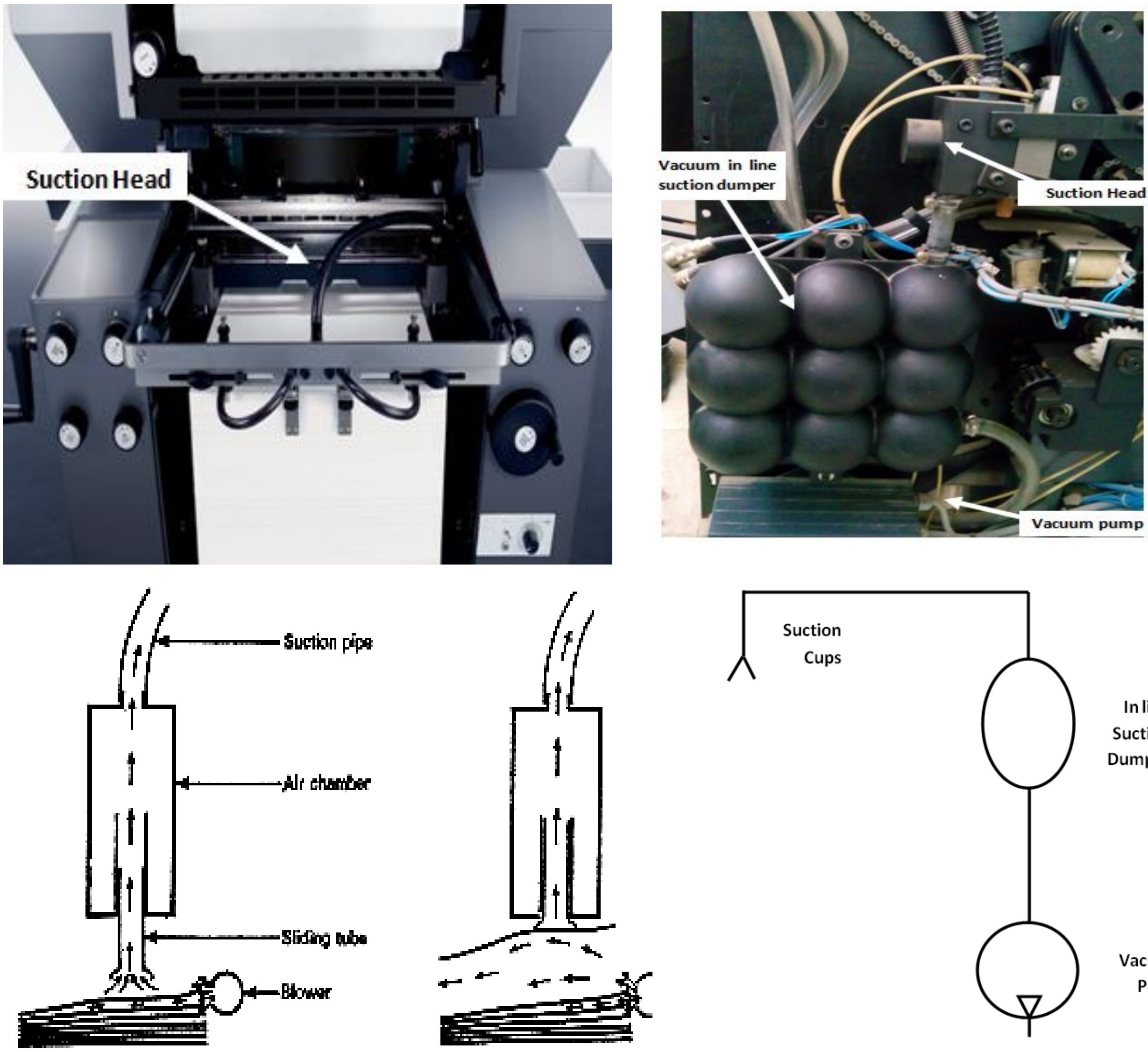

Fig. (1) Quick master printing machine paper feeding mechanism equipped with in line suction vacuum damper.

The under pressure generated in the vacuum pump is in the pulsating form. The in line suction vacuum damper has the function to damp the vacuum pulsation into a steady state manner with maintaining the under pressure that could pick up the paper.

Many researchers study the vacuum system performance from a different point of views. A vacuum system for picking up and accumulating runoff from sprinkler and overland-flow infiltrometers has been described. This system is much simpler than the runoff recirculation system of the Purdue sprinkler infiltrometer [1]. Vacuum suction cups are used for sticking the robot to walls to be climbed. Wall-climbing robot intended for inspection in nuclear power plants has been developed. The robot, small in size and modular, is made up of pneumatic components exclusively [4]. In the same manner a non-actuated glass-curtain wall-cleaning robot has been described. The robot hasn't its own driving mechanism, but it can move on smooth glass surfaces depending on its own gravity and the lifting force of the trolley crane on the roof while adhering to the surfaces using dual vacuum suction cups [9].

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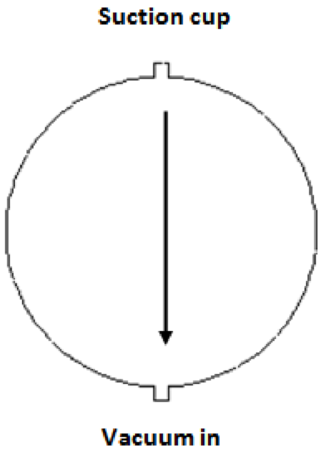
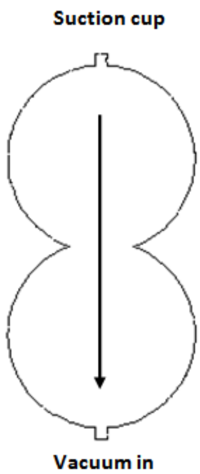
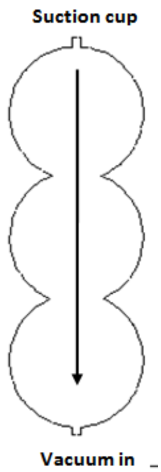


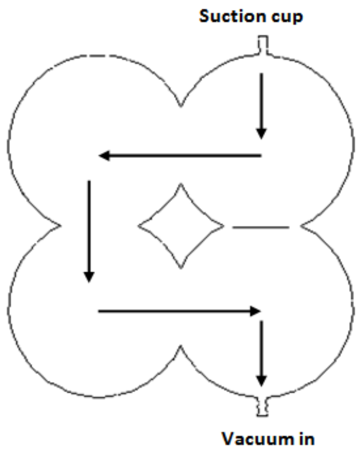
a) one chamber damper



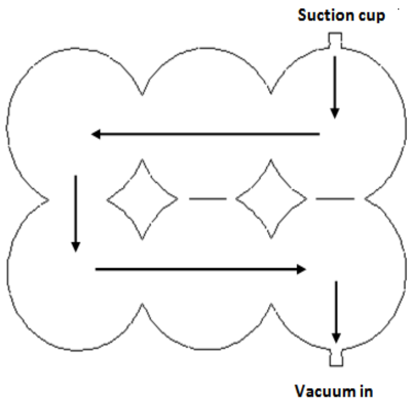
b) 2 chambers damper



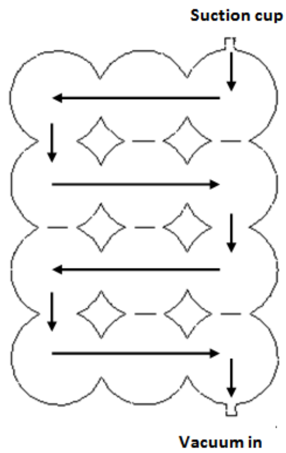
c) 3 chambers damper



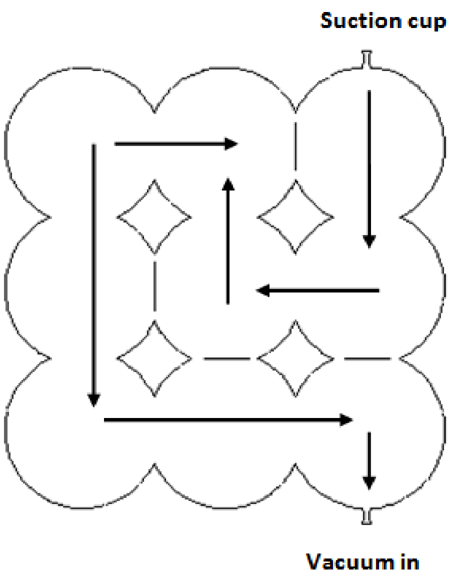
d) 4 chambers damper



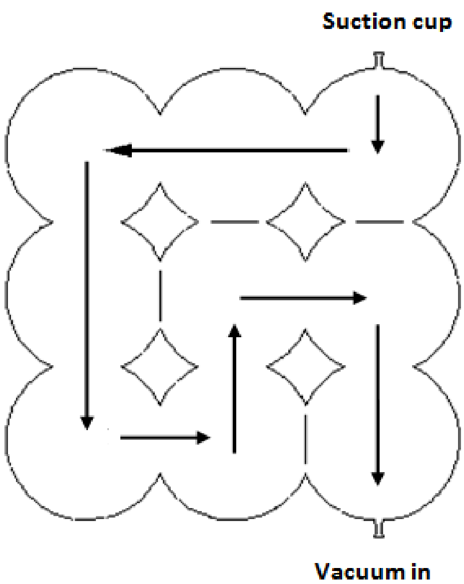
e) 6 chambers damper



f) 12 chambers damper



g) 9 R chambers damper



h) 9 chambers damper

Fig. (2) Mid-section of the vacuum suction damper with different chambers matrix and different flow path

A review of the vacuum dewatering literature detailing the empirical and theoretical work done to-date has been presented. A thorough description of the significance of airflow and associated convective mass transfer during vacuum dewatering is then described [7]. In the area of material gripping for delicate material a new gripping principle based on a novel Coanda effect ejector meeting these challenges gas been described. This ejector allows the construction of a slim, plate-shaped vacuum gripper with multiple independent suction heads. Each suction head is powered by a newly patented lateral Coanda ejector that ensures gripping power on all soft or porous materials [11]. Also, a new approach to reduce handling fragile and surface-sensitive damage of components as the thin wafers and flat panel necessitate has been presented. A new pneumatic levitation for non-contact handling of parts and substrates using negative pressure (vacuum) has been proposed [10] and in the same way with the MEMS assembly [13]. To eliminate the dust collecting in a parabolic cavity, a thermal numerical analysis of a novel vacuum cavity parabolic trough collector in which the top and the sides of the trough were covered with borosilicate sheets and a vacuum was assumed inside the cavity. The typical vacuum tube used in conventional troughs was replaced by a bare stainless steel pipe with selective coating [15]. However on the other hand other researchers are interest in the paper feeding in the printing machine but by using a smart mechatronic system as described in [8].

In the present work the effect of the in line suction vacuum damper internal construction and flow path with fixed volume on the dynamic performance of vacuum paper gripping system has been studied. Up to our knowledge there is no analytical model to explicitly characterize this phenomenon. The in line suction damper presented in this work has been constructed by a multi-chambers in matrix form. A series of in line suction dampers with constant volume and different chamber matrix construction has been introduced. Unsteady mathematical model for the in line suction damper has been developed. The effect of in line suction damper chambers matrix on the dynamic performance of vacuum system, of paper feeding in offset printing machine, has been studied at different inlet vacuum pressure oscillations.

2. Fluid Flow Analysis

The fluid flow analysis method could be used to show the in line suction vacuum damper performance characteristics in the paper feeding in offset printing machine. Therefore, the computational fluid dynamic (CFD) technique is used to study the behavior of the flow through the damper chambers at different vacuum pressure amplitude and frequency. This method can be used to predict the performance of the vacuum suction head for paper feeding in the quick master offset printing machine shown in Fig. (1). In the following fluid flow field and pressure distribution through the 3-D suction damper with different flow path, as shown in Fig. (2), are simulated by using the CFD program FLUENT. The simulation results are used to predict the behavior of the flow in suction damper with different chambers matrix and different flow path in the dynamic performance of the paper feeding suction head.

2.1 Governing Equations

The effect of pressure on the area-related mass flow rate as a function of Avogadro constant and molar mass of air at different temperature is modeled using the following equations [14]:

$$\dot{m}_A = Z_A \,.\, m_T = \sqrt{\frac{M}{2\pi \,.\, K.\, T \,.\, N_A}}\,.\, p \qquad (1)$$

$$Z_A = \sqrt{\frac{N_A}{2\pi \,.\, K.\, T \,.\, M}}\,.\, p \qquad (2)$$

$$m_T = \frac{M}{N_A} \tag{3}$$

$$N_A = \frac{R}{K} \tag{4}$$

The turbulent flow, due to the vacuum pulsating flow inside the damper chambers, has been modeled by two-equation models. That the solution of two separate transport equations allows the turbulent velocity and length scales to be independently determined. In this work the RNG K-ε model has been used to model the turbulence of the flow inside the suction damper chambers due to the inlet vacuum pulsation. The RNG k-ε model was derived using a rigorous statistical technique [3]. This model is derived from the instantaneous Navier-Stokes equations, using a mathematical technique called renormalization group methods. Equations (5) and (6) represent the RNG k-ε turbulence model.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k\, u_i) = \frac{\partial}{\partial x_i}\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\epsilon - Y_M + S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon\, u_i) = \frac{\partial}{\partial x_i}\left(\alpha_\epsilon \mu_{eff} \frac{\partial \epsilon}{\partial x_j}\right) + C_{1\epsilon}\frac{\epsilon}{k}(G_k + C_{3\epsilon}G_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} - R_\epsilon + S_\epsilon \tag{6}$$

Where: $C_1\varepsilon = 1.42$, $C_2\varepsilon = 1.68$ [3], [14].

The effective viscosity μ_{eff} that used in modeling the turbulence kinetic energy (k) and its dissipation rate (ε) could be calculated integrally from equations (7) and (8).

$$d\left(\frac{\rho^2 k}{\sqrt{\epsilon\mu}}\right) = 1.72\,\frac{\hat{v}}{\sqrt{\hat{v}^3 - 1 + C_v}}\,d\hat{v} \tag{7}$$

$$\hat{v} = {}^{\mu_{eff}}/_{\mu} \tag{8}$$

However, the term Rε could be calculated using equation (9).

$$R_\epsilon = \frac{C_\mu \rho \eta^3 \left(1 - {}^{\eta}/_{\eta_o}\right)}{(1 + \beta\eta^3)}\frac{\epsilon^2}{k} \tag{9}$$

Where: $\eta = S_k/\varepsilon$, $\eta_0 = 4.38$, $\beta = 0.012$ [3] [14].

2.2 Mathematical Models Preprocessing and Solution

The mathematical models have been performed for a different suction damper chamber matrix construction and different inside flow path. The volume is constant for all suction dampers construction regardless the internal construction and flow path for 9 chamber damper, Fig. (2). The mathematical models have been drawn by using Inventor program. The models have been meshed by using the mesh program under the ANSYS work bench. The numbers of nodes in different models are checked and have been found that the models solutions are number of nodes independent. The previous equations have been used to model the flow filed and the pressure distribution inside the in line vacuum suction damper. The time dependent (unsteady) models at different vacuum pump pulsating pressure frequency and amplitude have been investigated.

2.3 Boundary Conditions

The solver state is pressure based absolute velocity formulations and transient in time dependant. The inlet is set as a pressure inlet in the form of time dependant for the inlet vacuum pulsating. It is stated by the user defined function (UDF) for an oscillating inlet in the form of sine wave as in Equation (10).

$$p_v = p_{vo} + p_{vA}\sin(\omega t) \quad (10)$$

The outlet is set as a pressure outlet at constant atmospheric pressure. The operating condition is set at absolute zero pressure.

2.4 Model Solution Results and Analysis

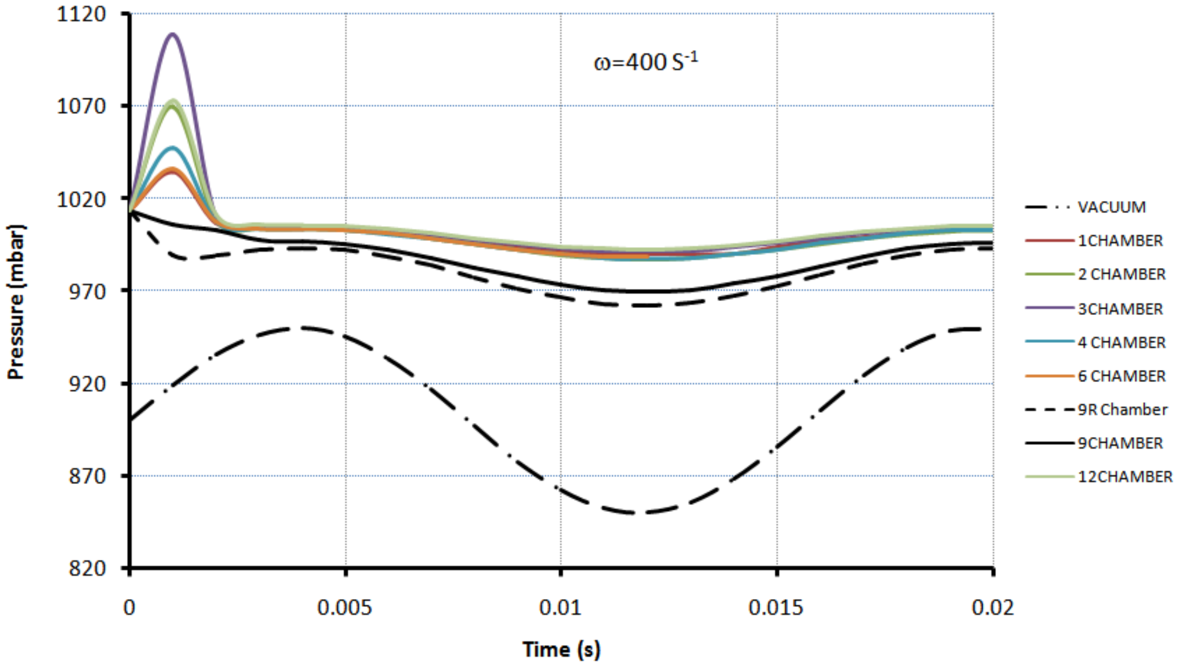
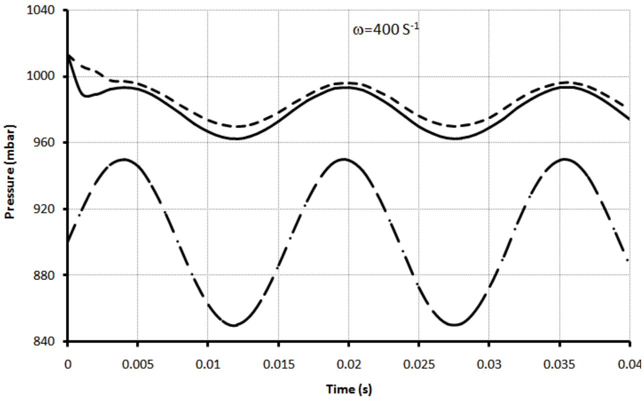
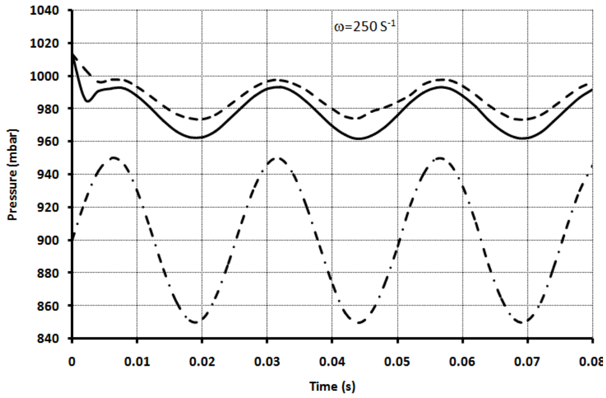


Fig. (3) Unsteady vacuum suction dampers performance mathematical model results at vacuum pump pressure 900mbar with pulsation of ω= $400S^{-1}$ and amplitude 50mbar.

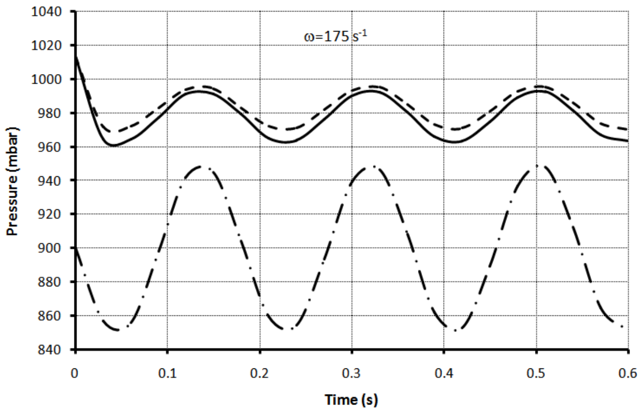
The unsteady RNG K-ε model has been used to model the fluid flow and pressure distribution inside the inline vacuum suction damper. The models solutions accuracy have been check and found that the solutions are independent on the number of model nodes. The pressure outlet is the vital parameter that effect on the amount of vacuum pressure that could pick up the paper from the paper pile in the feeding system of the printing machine.



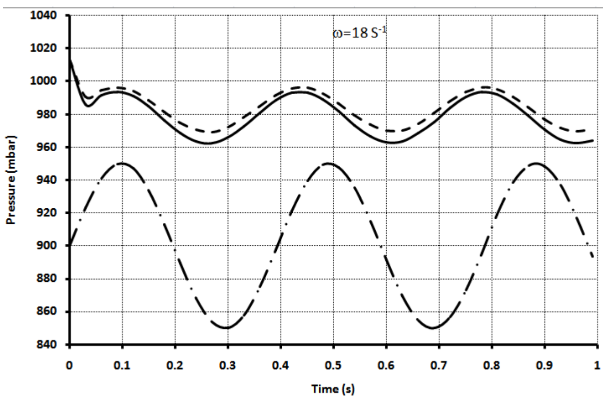
a) ω= 400S^{-1}



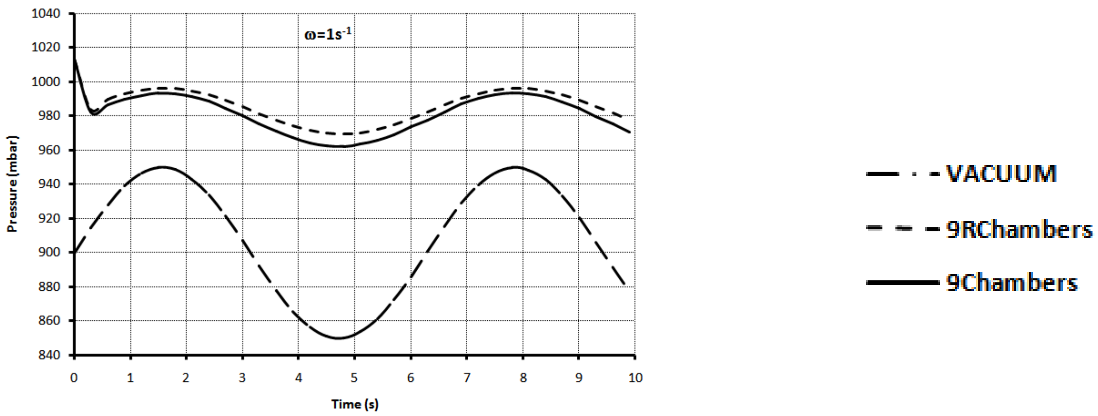
b) ω= 250S^{-1}



c) ω= 175S^{-1}



d) ω= 18S^{-1}



e) ω= 1S^{-1}

Fig. (4) Unsteady vacuum suction dampers performance mathematical model results for 9 chamber matrix with different flow path at vacuum pump pressure 900mbar with different pulsation oscillations of and amplitude 50mbar.

The model results at different damper chamber construction with constant volume and different pulsation frequency show that most of dampers construction damp the vacuum and neutralized near the atmospheric pressure that could not generate the force to lift the paper from paper pile, as shown in Fig. (3). Only the inline suction damper with 9 chambers that keeps the vacuum pressure at the level that could generate the force to pickup the paper from the pile as shown in Fig. (3).

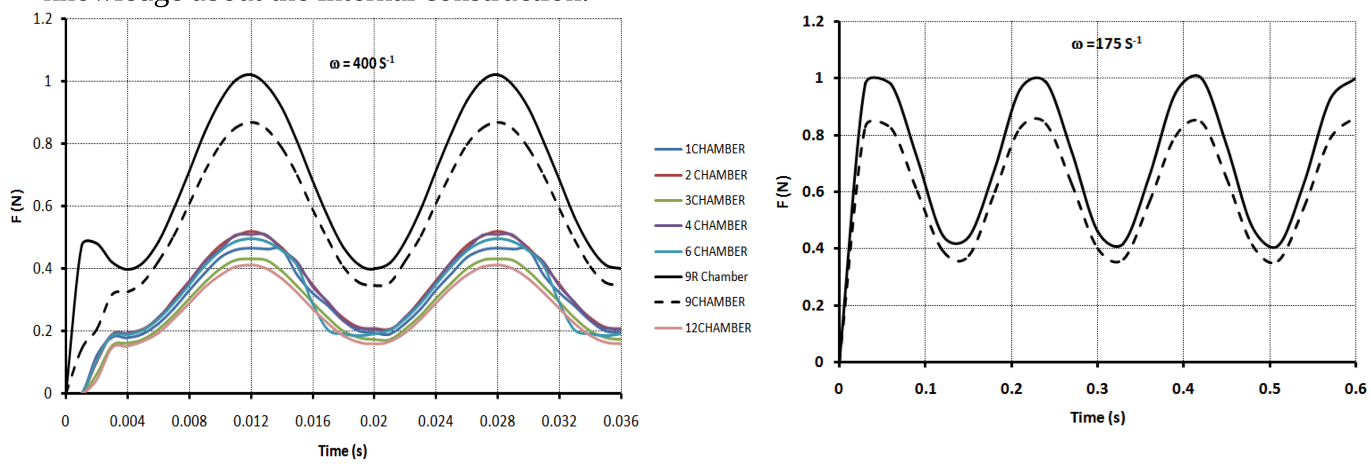
The suction damper with 9 chamber matrix with different flow path gives the same behavior of the vacuum oscillating pressure at ω= 400S^{-1}. The difference in both flow path of 9 chamber damper is at vacuum oscillation anti-peak as shown in Fig. (4). However, at oscillation peak the results are approaching the same values at damper outlet. The suction damper with 9 chamber construction damping maintains the behavior of vacuum oscillation as shown in Figs. (4) (a-e). At low vacuum pulsating oscillation a lead phase shift has been appeared at damper output and both flow paths gives almost the same difference at peak and antipeak values.

The under pressure force (F) necessary to lift paper from paper pile has been calculated using equation (11).

$$\sum_{i=1}^{n} \frac{(p_{atm} - p_v)}{A_h} > m_p \, g \, \cos\theta_p \tag{11}$$

Where: n=30 holes, m_p=0.08 kg, d_h=5.5 mm, θ_p=15^o [6]

Fig. (5) Shows the unsteady paper pickup force produced from different damper construction. The whole studied damper construction except the both 9chamber design damping the vacuum pressure and the resultant produced force due to the pressure difference hasn't the strength to pickup the paper from the paper pile as shown in Fig. (5-a). In the present work, the 9 chamber damper has been studied in two different flow paths for the lack knowledge about the internal construction.



a) ω= 400 S^{-1} b) ω= 175 S^{-1}

Fig. (5) Unsteady vacuum suction dampers paper pickup force for different chamber matrix with different flow path at vacuum pump pressure 900mbar with oscillations amplitude 50mbar.

The difference between different flow path 9 chamber damper are in the range of 18% at peaks and anti-peaks regions and about 5% in the transient regions as shown in Fig. (5-b). The oscillation of vacuum pulsating has been effect on the periodic time not on the value of the resultant vacuum force acts on the paper. Both 9 chamber flow path design are useful and could be used as an inline suction line vacuum damper in the paper feeding mechanism of printing machine.

3. Conclusions

In the present work the effect of the in line suction vacuum damper internal construction and flow path with fixed volume on the dynamic performance of vacuum paper gripping system has been studied. The in line suction damper presented in this work has been constructed by a multi-chambers in matrix form. A series of in line suction dampers with constant volume and different chamber matrix construction has been introduced. Unsteady mathematical model for the in line suction damper has been developed. The effect of in line suction damper chambers matrix on the dynamic performance of vacuum system, of paper feeding in offset printing machine has been discussed. The unsteady paper pickup force produced from different damper construction has been introduced. It has been concluded that both 9 chamber flow path design are the most useful design that could be used as an inline suction line vacuum damper in the paper feeding mechanism of printing machine. The rest of bumpers constructions are not a good choice for this type of industry.

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