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REDUCTION OF NOISE AND VIBRATION FROM BEARING LOADED SHAFTS IN PHOTOCOPIERS

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1. INTRODUCTION

Unwanted squeaks and vibrations arise from bearing loaded shafts when minute toner carrier beads become lodged in bearing pads and stick slip friction occurs, since no external lubrication is permissible in such paper handling systems. (Fig 1). Toner carrier beads are required to transfer toner to the photoreceptor in the reprographics or development process of photocopying. The squeaks cause significant customer complaint and dissatisfaction and the worn contaminated parts required replacing on a regular basis by service engineers.

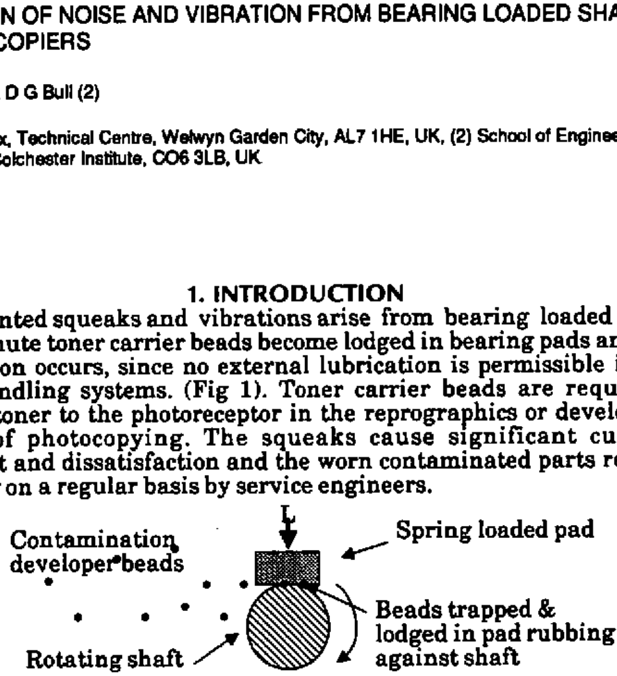

Figure 1. - Contamination of mechanism.

2. INVESTIGATION

The shaft has feed rollers which are loaded and able to move and register paper through the machine. The subsystem is called the 'Registration Assembly', (Fig.2). It's function is to feed paper through to the photoreceptor and adjust the lead edge position and registration of the paper so ensuring high copy quality The load is applied with polymer bearing pads resting on the upper edge of the shaft pushed down by two torsion springs.

A Test Rig was designed and built to represent and isolate the sprung loaded bearing pad on a rotating shaft. The Rig allows easy interchange of the shaft and bearing pads made from different materials, whilst maintaining the geometry. The shaft was driven by an electric motor through a pulley system. The position of the pad on the shaft could be moved allowing different positions on the same shaft. A small acoustic enclosure was placed over the motor to reduce background sound levels to a minimum. The normal load and relative velocity between the pad and the shaft was consistent throughout the measurements, so the only variable parameters in the system were the materials used for the bearing pad and the shaft and whether the system had been contaminated with developer beads or not. Contamination was achieved artificially by dropping toner developer beads into the path between the pad and shaft using a fine brush, ensuring a few become trapped.

All the measurements were carried out in a semi anechoic chamber (absorption coefficient of 0.9) with background levels 30 dB(A), 55 dB(L). An accelerometer was attached, with Bees wax, to the housing above the pivot point of the torsion springs to measure the vibration acceleration. A microphone was placed in the near field 5cm above the pad location to measure the relative sound pressure levels in 12th octave frequency spectra.

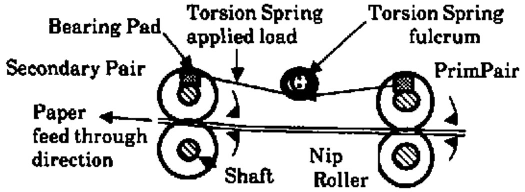

Figure 2.- Major elements in the mechanism.

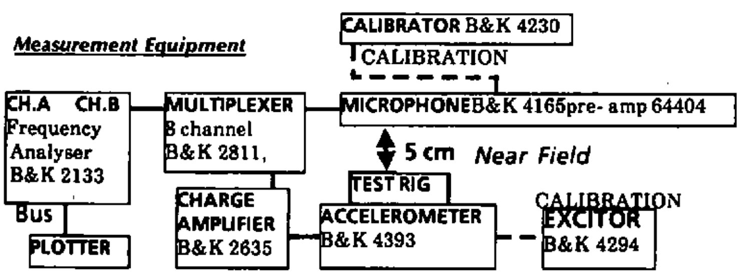

Figure 3.- Equipment set-up

Initially background measurements were made with the drive motor and belt running light. The shaft and bearing pad combination selected (Fig. 4), were run for about thirty minutes to settle in, and spectrum measurements made in uncontaminated conditions. Then contamination was added, in the path between the two surfaces. The rig was left to run in for a period of time until audible squeaks could be heard.

SHAFT MATERIALS	PAD MATERIALS
Chrome Plated Steel	Nylon:- 10% Carbon 15% PTFE
ZincChromatePlated Steel	Delrin:- AF 500- PTFE fibres
Stainless Steel	Acetal:- 20% PTFE 2% silicon
Aluminium Alloy	Sintered Phosphor Bronze:- 90% Cu 10 % Sn Oilite SE30
Free M/c Hard Brass	Developer Beads ∅0.8 microns ferrite beads with 5% toner.

figure 4.- Material combinations used

3. RESULTS

The best and worst shaft materials used in combination with the Delrin pad where tried with the Acetal and Nylon bearing pads. Finally, the Chrome Plated and Brass shafts were tested with Sintered Bronze pads which were specially developed to reduce noise and vibration levels. Full results are listed in a Project Report [1]

		No Contamination				With Contamination					
shaft material	pad material	SPL dBA	dB LIN	ms^{-2} A	ms^{-2} LIN	SPL dBA	dB LIN	ms^{-2} A	ms^{-2} LIN	shaft hardness ROCK. B	Av. Wear um
Chrome	Acetal	60.7	64.3	0.58	0.79	96.0	98.0	18.7	36.4	92.5	0.65
Zinc	Delrin	71.2	73.9	0.65	0.86	89.1	92.8	14.6	29.0	91.5	0.61
Chrome	Delrin	61.2	64.6	0.54	0.72	87.8	93.6	23.2	72.8	92.5	0.65
Chrome	Nylon	61.2	64.0	0.76	0.9	84.7	92.2	9.0	23.7	92.5	0.47
Brass	P.Bronze	62.8	66.6	0.62	0.98	77.6	79.7	2.02	2.17	51	5.4
Stainless	Delrin	60.6	65.2	0.52	0.68	75.6	77.9	9.78	20.7	100	1.35
Brass	Delrin	62.4	64.9	0.83	1.11	67.8	70.2	1.67	1.86	51	4.1
Brass	Acetal	62.9	67.1	0.82	1.13	66.9	72.2	1.67	2.21	51	2.1
Brass	Nylon	60.5	63.6	0.62	0.81	65.8	69.5	1.62	1.84	51	1.52
Alumin.	Delrin	63.4	67.5	0.79	1.05	63.1	67.1	0.76	1.0	47.5	2.25
Chrome	P.Bronze	61.0	63.9	0.61	0.84	60.8	84.8	0.78	0.85	92.5	1.2

figure 5.- Material Combinations Tested and Results

The SPL levels before contamination show little difference between each material combination. (fig. 5) The acceleration levels are more revealing and display greater distinguishing characteristics because the acceleration scale is a linear. They show that the highest levels of acceleration are for Delrin and Acetal with Brass giving 1.11 ms^{-2} (L) and 1.13 ms^{-2} (L) respectively.

After contamination the overall SPL and acceleration levels for the material combinations are much higher. The highest levels of SPL were for the Delrin pad on Chrome Plated Steel or Zinc Chromate and the Acetal pad on the Chrome Plated Steel shaft. The high SPL levels range from 85 dB(A) 92 dB (L) to 96 dB(A) 98 dB (L), characterised by a high pitched audible 'squeal'. The lowest SPL levels after contamination where for the following combinations; Delrin on Aluminium and Brass; Nylon on Brass; Acetal on Brass and Sintered Bronze on Chrome Plated steel.

With Sintered Bronze on Chrome Plated Steel there is a vast improvement, with a reduction from 96 dB (A) to 60.8 dB(A), a total reduction of 35.2 dB(A), when switching to sintered bronze instead of the polymer pads. A very high vibration reading for Delrin on Chrome plated steel at 72.8 ms^{-2} (L) reduced to 0.85 ms^{-2} (L) with the Sintered Bronze pad fitted. Vibration levels with the sintered bronze pad on chrome plated represent the lowest acceleration levels, (fig 5).

The sound pressure level spectra indicate broad band noise with peak levels extended over the high frequency range from 2 to 22 kHz. The results indicate that friction noise signatures have a well defined structure, with common and randomly occurring sharp pulses, noticeably at 7.29 kHz, 14.5 kHz, 20.5 kHz and 21.8 kHz. These resonant frequencies are likely to be due to the resonance of the beads and wear debris, and/or resonant vibrations of the pad itself near its natural frequency.

4. DISCUSSION

When two solid surfaces are in close contact the intermolecular forces at the touching surfaces can lead to interfacial adhesion and the formation of junctions between the surface asperities causing friction, wear and resulting in the 'Stick Slip' phenomenon. (fig 6).

The beads worsen the problem if they become trapped, because they act as a kind of knife edge or tool cutting edge and as they vibrate resonantly. Microscopic analysis found significant impacted developer beads in all the polymer pads except the sintered bronze.

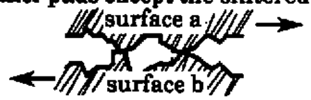

Figure 6.- Magnified representation of extreme boundary conditions.

Stick slip vibrations are self sustained oscillations induced by dry friction. There appears to be two characteristic phenomena which cause the stick mode to occur:- i)Resistance against the start of motion, from equilibrium, elastic - two surfaces stick, the base of the asperities deform elastically in slip mode. ii)Resistance against an existing motion, plastic deformation, asperities deform elastically [2],[3].

The Harness will relate to the rate of wear of the shaft materials. (fig 5). Therefore the ultimate shear strength and surface finish is important in considering the shearing of the junctions between the rubbing bodies.

5. CONCLUSIONS

The high levels of noise and vibration observed seem to be chaotic in nature probably as the beads, microscopically observed embedded between the surface asperities, vibrate randomly near to their natural frequencies[4]. Hence it is very difficult to determine an empirical relationship between noise and material properties.

The best combination was the relatively hard sintered bronze pad on the harder chrome plated steel shaft. The harder the material characteristics the more difficult for foreign bodies to become lodged between the asperities. the noise appears to be far greater when the beads embed themselves in the softer materials.

Viscous linear damping characteristics of the copper in brass, aluminium alloy and sintered bronze pad reduces noise. PTFE and oilite additives and other lubrication additives within the materials can improve matters, but the overriding factor is the relative hardness of the bearing pad material where contamination is a likely possibility.[5]. The Sintered Bronze pads have been life tested and successfully incorporated into Rank Xerox copiers. Service requirements have reduced and customer satisfaction has improved.

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