A Nitto Kohki White Paper

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THE LONG-TERM ADVANTAGES OF LINEAR MOTOR FREE PISTON SYSTEM PUMPS AND AERATORS

"Simplicity is the ultimate sophistication."
— Leonardo da Vinci

INTRODUCTION

As technology proliferates and advances, certain principles hold over time. The power of simplicity in design is one of them.

Leonardo's assertion reflected what William of Occam postulated the century before him, what is commonly known as Occam's Razor. Put simply, Occam's principle can be stated as: among competing hypotheses, the one with the fewest assumptions should be selected. A recent article on the Interaction Design Foundation website notes how Occam's Razor relates to design:

In design, Occam's Razor encourages us to eliminate unnecessary elements that would decrease a design's efficiency. So, when two products or designs have the same function, Occam's Razor recommends selecting the simpler. Therefore, when evaluating your designs, analyze each element and remove as many as possible, without compromising the overall function. This should ensure that you remain with elements you have minimized as much as possible, but which still work perfectly.1

This paper examines the idea of design simplicity as it relates to compressors and vacuum pumps used in both the device manufacturing industry at large and the medical device manufacturing industry in particular, comparing and contrasting conventional design (i.e., motor-driven and diaphragm) with the linear motor free piston system design.

Small onboard compressors and vacuum pumps have been used in the device manufacturing industry as an alternative energy transfer mechanism to electrical, mechanical or hydraulic energy for many years. Pneumatic energy transfer offers features unattainable with other energy transfer mechanisms—providing an infinite, safe, clean and cost-effective energy source— and facilitating energy transfer in ways that other media cannot easily match.

Consider the medical device industry. While they may not be the most headline-grabbing components in this fast moving sector, pneumatic circuits are among the most important, as they offer the most flexibility and adaptability for a wide range of applications. This is especially so for human interface applications, where air compressors and pumps offer exceptional control and reliability. They permit energy transfer without risk of electrical shock, and the energy can be transferred uniformly, precisely, delicately, and comfortably to a patient. Pneumatic energy allows designers of medical devices to apply energy remotely while precisely controlling the fluid transfer interface in an optimal manner for human interaction (e.g., through their ability to conform to any shape).

But how these pneumatic devices accomplish that work differs significantly according to their design.

DESIGN CONSIDERATIONS

The linear free piston operating principle employs a much simpler design. Linear piston pumps eliminate the transmission and combine the motor and pump into a single unified design, with only one moving part – the piston.

Conventional motor-driven pumps use electromagnetism to create rotational energy, which gets converted to translational motion through an offset crankshaft and connecting rod mechanism. These designs use bearings to reduce the friction within the rotational-to-translational power transmission for moving the piston back and forth. Therefore, conventional pumps have three separate mechanisms: motor, transmission, and pump.

Further, large motor-driven pumps rely on a fan blade on the motor shaft for cooling air. Typical OEM motor-driven pumps do not use external fan cooling, and as such they tend to run hot.

Diaphragm pumps move a rubber diaphragm up and down, alternately pulling and pushing air through inlet and outlet valves above the diaphragm. When the diaphragm tears— the typical failure mode— the compressor is said to have failed catastrophically. There is no more airflow.

The linear free piston operating principle employs a much simpler design. Linear piston pumps eliminate the transmission and combine the motor and pump into a single unified design, with only one moving part— the piston. The piston assembly is a spring attached to a piston, with the spring-mass assembly designed to resonate at the input frequency (i.e., 60 or 50 Hz). A silicon diode (i.e., an electronic check-value) between the electromagnetic coils converts the full wave input into a half-rectified sine wave. The result is a complimentary pulsating electromagnetic field energizing a resonant spring-mass piston assembly. The piston is pulled back for the inlet stroke when the coil is energized and the spring pushes the air out of the front cylinder when the electromagnetic field is de-energized.

Linear piston assemblies employ wear bearings (e.g., from rugged materials like Rulon) on the front and back outside diameters of the piston. These surfaces slide inside precision machined and treated cylinders for ultra-low friction.

Consider a couple of differences these design differences point to.

In contrast to the inherent "hot running" issues of motor-driven pumps, air passes through linear piston pumps, over the electromagnetic coils, and out of the enclosure— taking the heat with it. This provides cooling without disturbing the environment.

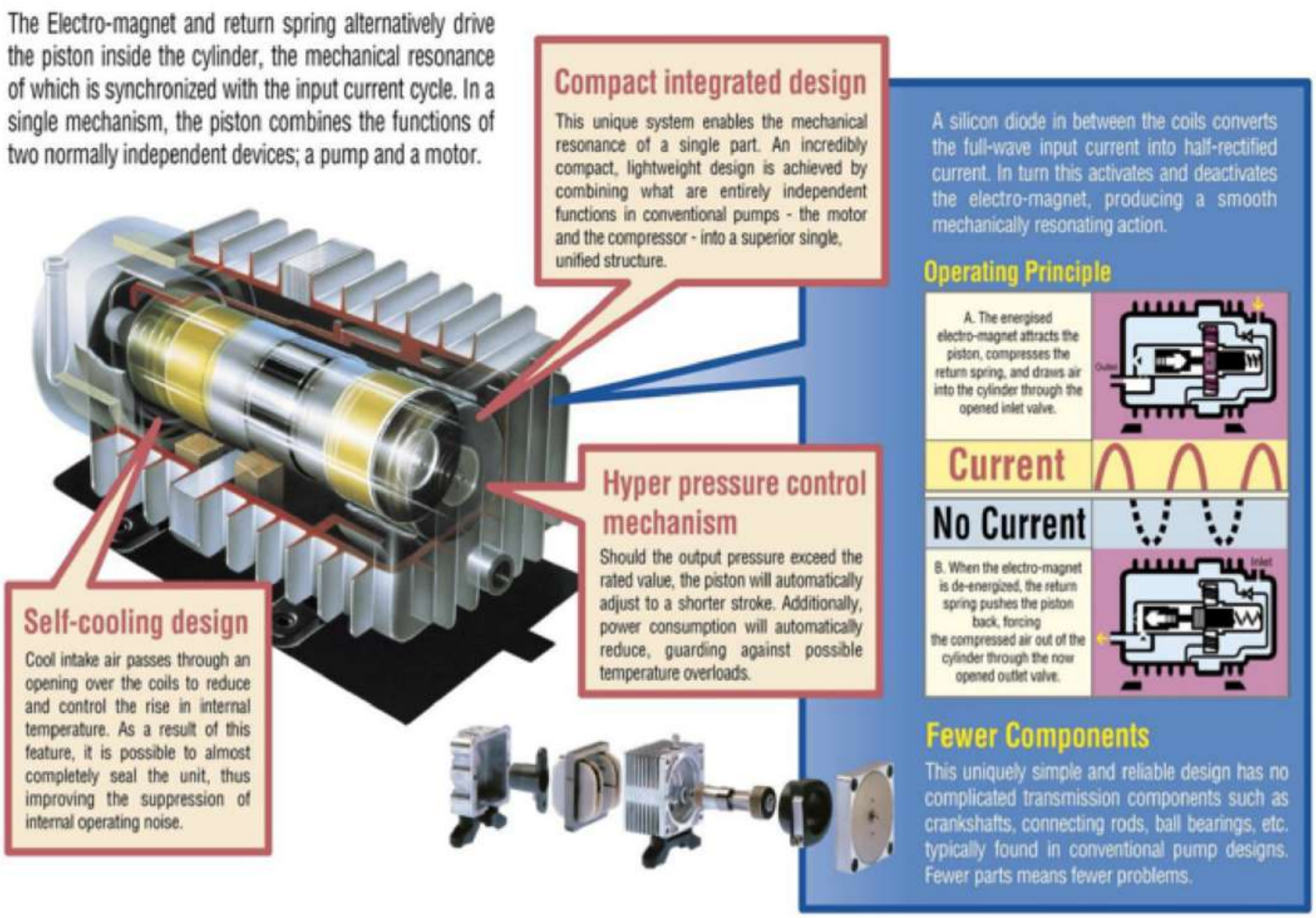
The Linear Free Piston design is also significantly different when the pressure exceeds the pump's rated value.

Conventional motor-driven pumps must operate within their designated operating pressure range; otherwise, the motor can break the pump by pushing it beyond its capacity, or the pump makes the motor bearings fail prematurely when the compression forces exceed motor and bearing limits, destructive heat builds, and failure ensues.

In contrast, when subjected to operating conditions that raise pressure in the pneumatic circuit, a linear-piston design automatically allows reduced piston stroke until the piston no longer pushes air out and the piston simply vibrates within the compressed air. The pumps stays like this until operating pressure decreases, then piston stroke increases, restoring flow at the lower pressure. Furthermore, as the piston stroke is shortened by the backpressure in the pneumatic circuit, the current draw drops too— so the electromagnetic coils generate less heat. The result is lower risk and longer performance life.

A CLOSER LOOK AT THE LINEAR MOTOR FREE PISTON DESIGN

The illustration below details the operating principle and overall simplicity of the linear-piston design.



When conventional motor-driven pump designs are compared to this, they are found not only to have greater risk (i.e., greater complexity), but are also significantly noisier, having roller bearings and sintered bearings more subject to degradation over time.

SIGNIFICANT BENEFITS

The simplicity and elegance of the linear piston design yields a range of significant benefits for device manufacturers; these include but are not limited to:

LOW POWER CONSUMPTION
Since the low mass piston is the only moving part, frictional losses are minimized, allowing lower starting and running current— and therefore greater energy efficiency. Related benefits are realized through lower temperature rise, which facilitates longer service life for the pump and other device components.

CLEANER OPERATION
All wearing surfaces of the linear piston pump use no oil, grease or other contaminating lubricants. The combination of a precision Teflon-sleeved piston with the "self-cooling, air-bearing" effect of the design assures that outlet air is completely oil-free.

LOWER NOISE LEVELS
By eliminating the need for transmission mechanisms or actuating linkages that create friction, the linear piston design creates a pump that is inherently quieter than conventional alternatives. Further, its near-sealed configuration also suppresses internal operating noises. No pump design has less ambient noise.

OVERLOAD PROTECTION
As noted above, as the pressure within the linear piston compressor increases, the piston stroke decreases. Along with this, electric current decreases. This minimizes the risk of failure or burnout from temporary overloads.

EXTREMELY LOW VIBRATION
Reducing the moving parts to one— the piston alone— minimizes reactive force vibrations to the pump body. Secondary vibrations are isolated and further absorbed through vibration isolation rubber mounting feet.

FAST RESPONSE
In frequent on-off short cycle applications, the linear piston design enables near instant response times through very low starting current— even in the presence of residual pressure.

PERFORMANCE OVER TIME
For many applications the "application specific" life expectancy of Linear Free Piston vacuum pumps and compressors may be well above the published life expectancy specification.

USE CASE SCENARIOS & FURTHER DESIGN DEVELOPMENTS

Linear piston pumps are produced in many standard sizes to accommodate a wide variety of applications. They are particularly suited to the medical device industry.

Examples of proven medical applications include Sequential Compression Devices (SCD). These types of devices improve circulation for diabetic patients, post-surgical patients, lymph-edema therapy, and bedsore prevention, to name just a few.

Linear piston pumps are ideally suited for such devices because they apply forces with air, so are highly controllable and apply uniformly distributed pressure to patients without risk of localized pressure or bruising. The use of pneumatics also eliminates the risk of electric shock. In an SCD, for example, the therapy garment is fitted with air tubes that connect between the patient and the controlling device isolating the electrical components in the device from the patient. Further, the exceptionally low operating noise allows patients to rest while receiving therapy.

Other industry applications of linear piston pumps include: Environmental sampling, positive pressure to assure clean environments, and vacuum hold-down and pick and place applications, and aerobic water treatment (both wastewater and aquaculture applications).

DC VARIATIONS

While the linear piston design relies on a half-rectified AC sine wave input; the pulsating current in a half-rectified AC input can be easily simulated with a chopped DC input by stopping the current 60 times per second with a simple reliable microelectronic circuit.

Manufacturers have developed special versions of linear piston pumps that employ low voltage (12 & 24 VDC) high efficiency electromagnetic coils with a built-in DC chopper circuit. These pumps operate at lower power levels and so are able to run cooler than their line voltage counterparts, and as such they enjoy even longer life expectancy. This allows engineers designing global market and portable products to utilize all the benefits of linear piston pump design with the advantages of a DC input.

FINAL CONSIDERATIONS

"That's been one of my mantras - focus and simplicity. Simple can be harder than complex: You have to work hard to get your thinking clean to make it simple. But it's worth it in the end because once you get there, you can move mountains."

– Steve Jobs

Linear piston pumps and compressors run quieter. They last longer. They consume less energy.

We began this paper by referencing a couple of innovators from 700 or years or so ago. We close it with an innovator from our own times to underscore the initial point — that certain principles hold over time, even in an age like ours, where technology accelerates at astonishing rates.

The linear motor free piston system design is a simple, focused design that has worked reliably in a host of industries since its commercialization in the 1970s. That it has done so points to the soundness and utility of the design, which has proven itself particularly well in applications where reliability and long-term performance are critical.

+ Diaphragms can tear; solid aluminum pistons can't.
+ A design that generates less heat and self-cools is less subject to the destruction heat can deliver— and the failure in its wake.
+ Energy efficiency and clean operation are increasingly important in an age where sustainable design has moved to center stage.

Linear piston pumps and compressors run quieter. They last longer. They consume less energy. These are simple points, but for many they are telling points, as they look to reduce risk and raise efficiencies as they meet the requirements of their specific applications.

If you have an application that requires a pump or compressor, and the advantages of the linear motor free piston system hold some appeal for you, we'd love to have a conversation. You can call us at **800-843-6336** or send an e-mail to get things started to: ***inquiry@nittokohki.com***

NOTES

1. Soegaard, Mats, "Occam's Razor: The simplest solution is always the best," Interaction Design Foundation, April 17, 2017; https://www.interaction-design.org/literature/article/occam-s-razor-the-simplest-solution-is-always-the-best