

ADVANCING MAN MACHINE INTERFACES THROUGH EMBEDDED STRAIN MEASUREMENT TECHNOLOGY

By: Jane Kamentser
VP, Bokam Engineering

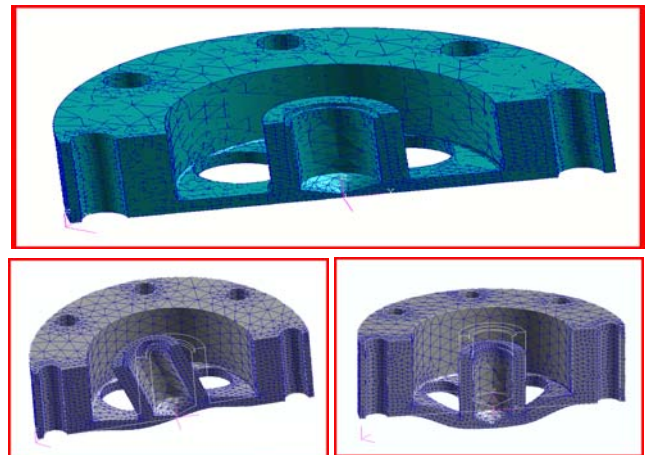
TODAY'S STANDARDS:

With the advent of more automation and greater computer control of most military and industrial and deep water machinery, the need to have a reliable man-machine interfaces that can withstand diving depth and prolonged exposure to salt water and other harsh environments has become imperative. Unfortunately, standard joystick and input device technology draws its heritage from the commercial input devices that were never meant for these harsh environments. Most of the joysticks used in military applications today are merely an upgrade of the joysticks you find in the electronic/game industry. Those that are more robust are extremely expensive due to the high cost of ruggedizing and sealing a technology never meant for this use. Input device applications break down into: position proportional, force proportional, and switching. In standard joysticks all three approaches required their own technology, technical solutions, packaging and signal processing, making going from one type of user interface to another extremely difficult.

In general, today's standard input device baselines utilize either: potentiometer, hall effect, or optically based technologies for position proportional devices; conventional or piezoelectric strain gages for force proportional; and standard industrial momentary switches for switching. All of these technologies have their own drawbacks that limit their usability in military environments. A quick summary of advantages and disadvantages can be found in Table 1. Suffice it to say none of them were developed specifically for the military or heavy industrial input device applications. The survivability of those devices in military and industrial applications can be directly attributed to the ingenious and rather complex packaging, mechanical designs and shielding designs created over the years by a wide range of very capable suppliers.

A radical new approach was needed that was based on a core technology that is easily adaptable to the stringent requirements of these demanding applications. This approach came when Bokam began to develop the finger cursor control-pointing device for the then new IBM laptops. Utilizing the technology originally developed for differential pressure measurement in automotive exhaust measurement, Bokam developed a miniature two axis (and later three axis) force sensor that resolved the input force into X, Y and Z component vectors. The development was further improved when the metal-based three-axis force sensor was developed. These innovations allowed for the creation of an entirely new approach to input resolution. Bokam's technology was based on a proprietary method of embedding strain sensitive materials directly into steel diaphragms which garnished a myriad of design and innovation awards for the company and it's engineering staff.

With the strain sensitive materials fused into the metal substrate directly, these force sensors eliminated organic binding or gluing materials required in the application of conventional strain gages. This new technology base created a multi axis design that boasted a co-planar, axis specific, strain sensitive bridge that was stable over time, temperature, and force application cycles.



MULTI-AXIS FORCE SENSOR MODEL
(MOTION EXADURATED)

Technology	Advantages	Disadvantages
Potentiometers	<ul style="list-style-type: none"> • Industrial versions available in low cost packages (military versions extremely expensive) • Position Proportional 	<ul style="list-style-type: none"> • Poor reliability • Require complex internal mechanisms • Prone to damage due to environments and dirt • Moving/rubbing parts wear easily • Low Life • Military and high reliability devices extremely expensive
Optical	<ul style="list-style-type: none"> • Low Cost • Position Proportional 	<ul style="list-style-type: none"> • Required complex internal mechanism • Prone to damage due to environments and dirt • Low life
Hall-effect	<ul style="list-style-type: none"> • Extremely Low Cost • Position Proportional 	<ul style="list-style-type: none"> • Extremely susceptible to EMI
Switches	<ul style="list-style-type: none"> • Low Cost 	<ul style="list-style-type: none"> • No position proportional options available • Noisy • Prone to damage due to environments and dirt • Low life • Poor reliability
Conventional strain gages	<ul style="list-style-type: none"> • Force proportional • No moving parts • Increased reliability over other technologies listed 	<ul style="list-style-type: none"> • High cost of strain gage application • Limited configurations • Cross-talk • Not time or temperature stable • Susceptible to noise • No position proportional options available

TABLE 1: CONVENTIONAL TECHNOLOGY TRADE STUDY

FORCE PROPORTIONAL INPUT DEVICES:

The application of these multi-axis force sensors in force proportional input devices was natural. The force proportional devices utilizing Bokam’s strain measurement technology offered some key advantages over the conventional joysticks. Without moving or rubbing parts and with the long life and environmental stability of Bokam’s embedded strain gage technology these force proportional devices boasted a long life (10,000,000 cycles) and environmental robustness in the presence of salt water, other corrosive agents and extreme temperatures that would damage conventional input devices

One of the best examples of the use of Bokam’s force proportional input devices was the Underwater Switch (Neptune Series) developed by Bokam for the US Navy. The device was envisioned as a non-contacting, non-audible, non-magnetic man-machine interface that provided two directional switching capability at extreme dive

depths and provided superior reliability and survivability in virtually any conditions.

Since the core of the device was really a multi axis force sensor, the device quickly grew into an entire family of one and two axis (two and four direction) input devices and switches. All of the devices in the product line had the same physical mounting and interface, the same underwater survivability, reliability and accuracy, but could be all things to all applications. The one axis switches could be used as two directional momentary or latching switches or one-axis force proportional input devices. The two axis devices (packaged in the same physical configuration as the one axis device could be used as a four position switch or a two axis input device (usable for both cursor control, or motion control applications).

This universal package offered superior performance and survivability in the harshness of environments, increasing the reliability of the host system many fold.

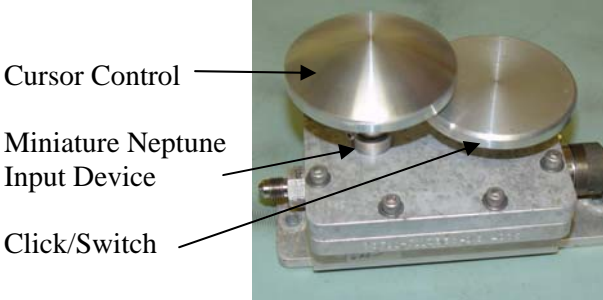
This simple approach allows Bokam to package the same basic configuration into a wide range of applications and uses.



**MINIATURE NEPTUNE
 SERIES INPUT DEVICES**

The force proportional systems carry certain advantages including higher precision, smaller stay-out zone in the system and due to the nature of the sensor technology water/environmental resistance. With Bokam’s patented co-planar strain measurement approach the complexity of the input device has been reduced to a diaphragm, a post and housing. Making this system the simplest of all input devices.

The sensor itself provides an analog, linear and proportional signal. The way the signal is used depends entirely on the signal conditioning electronics that come with the device. In the submersible systems the electronics are located inside the host system housing or a structure that holds all of the input devices. The signal conditioner processes the analog signal from the sensor into a control signal required by the application. In the case where the input devices are used as switches, the electronics have a pre-set threshold that activates the switching of the incoming system specific signal or current. In the case of motion or cursor control the signal from the input device is amplified and then formatted to suit the requirements of the end application.

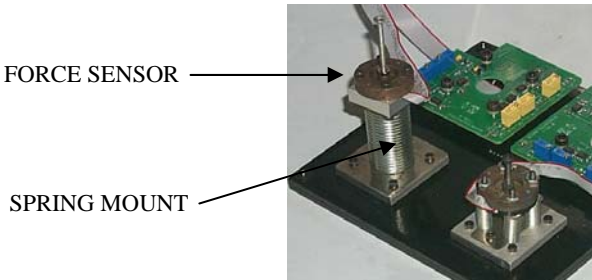


**UNDERWATER PALM
 CONTROLLED MOUSE**

POSITION PROPORTIONAL INPUT DEVICES:

Despite the significant advantages of force proportional systems and their uses in a wide range of applications there are some drawbacks. Experiences with old-fashioned strain gage based force proportional fly-by-wire input devices in fighter jets made people less than willing to use stiff-stick input devices in mobile or vehicular applications. Whereas the stiff-stick approach was substantially more precise and applicable in positioning applications, pilots and operators trained in and experienced with the use of position proportional devices found the force proportional devices more difficult to get used to.

In order to overcome this stumbling block, and merge the advantages and reliability of the force proportional devices with the user feedback of the position proportional devices Bokam developed a unique mechanical design. By combining a multi-axis force sensor with a compliant input lever mechanism Bokam’s engineers were able to create a device that utilized the non-moving, non-rubbing sensing elements of the force proportional sticks with a moving input lever that simulated position proportionality in the stick. Therefore applications, where position proportional input devices was a key to usability, could still take advantage of the increased reliability of the non-moving devices.



**EARLY DESIGN MODEL OF FORCE
 SENSOR WITH SPRING INTERFACE**

(Current systems have reverse configuration with force sensor hard mounted and spring interfacing with the input/grip element)

THE MODULAR SYSTEMS

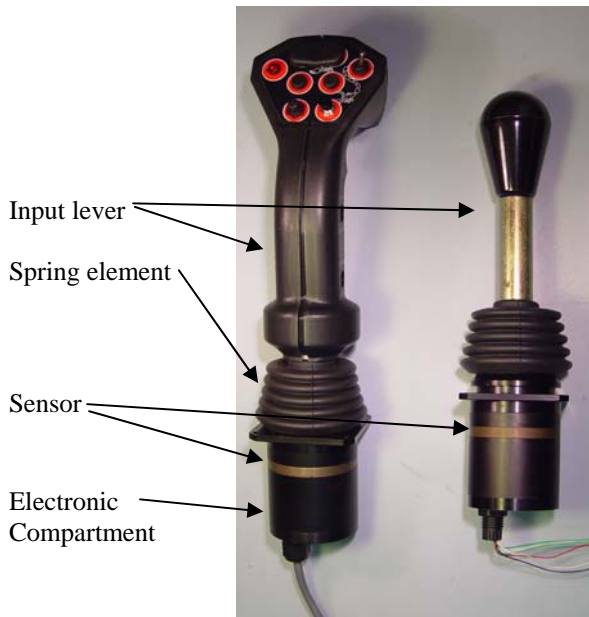
Regardless of application or specific functionality the Bokam input device consists of four main building blocks:

- Force measurement sensor (one, two or three axis)
- Signal Conditioning Electronics
- Force sensor – hand interface (stiff stick grip or compliant mechanism)
- Mounting mechanism and/or housing

With great variations in requirements from application to application in the military and heavy industrial markets, Bokam developed a modular approach to input device design and development. With each application sometimes requiring only a handful of input devices, advantages of mass produced joysticks in cost reduction opportunities were not present. In this, the Bokam design had a serious advantage. All input devices, whether force proportional or position proportional, having a multi-axis sensing element as the base meant that input device could be made up of interchangeable building blocks that were standard. These standard building blocks allowed low volume applications to take advantage of higher volume production cost effects. In addition, the building block approach also meant that the same mounting configuration could be used for both force proportional or position proportional applications. This modular approach allowed commonality between various applications even if the mechanical input usability was different.

Using this building block approach, Bokam's customers are able to put together input devices that meet their specific requirements. Each building block drawing its heritage from proven life tested and field-tested applications.

Another key advantage to the modular approach is that modifications to any particular building block that may be required to meet the requirements of the end system do not affect other building blocks. This allows the use of heritage qualification and minimizes delivery times and cost. This approach is key in an environment where requirements are harsh, volumes may be low but cost and schedule are still a major factor.

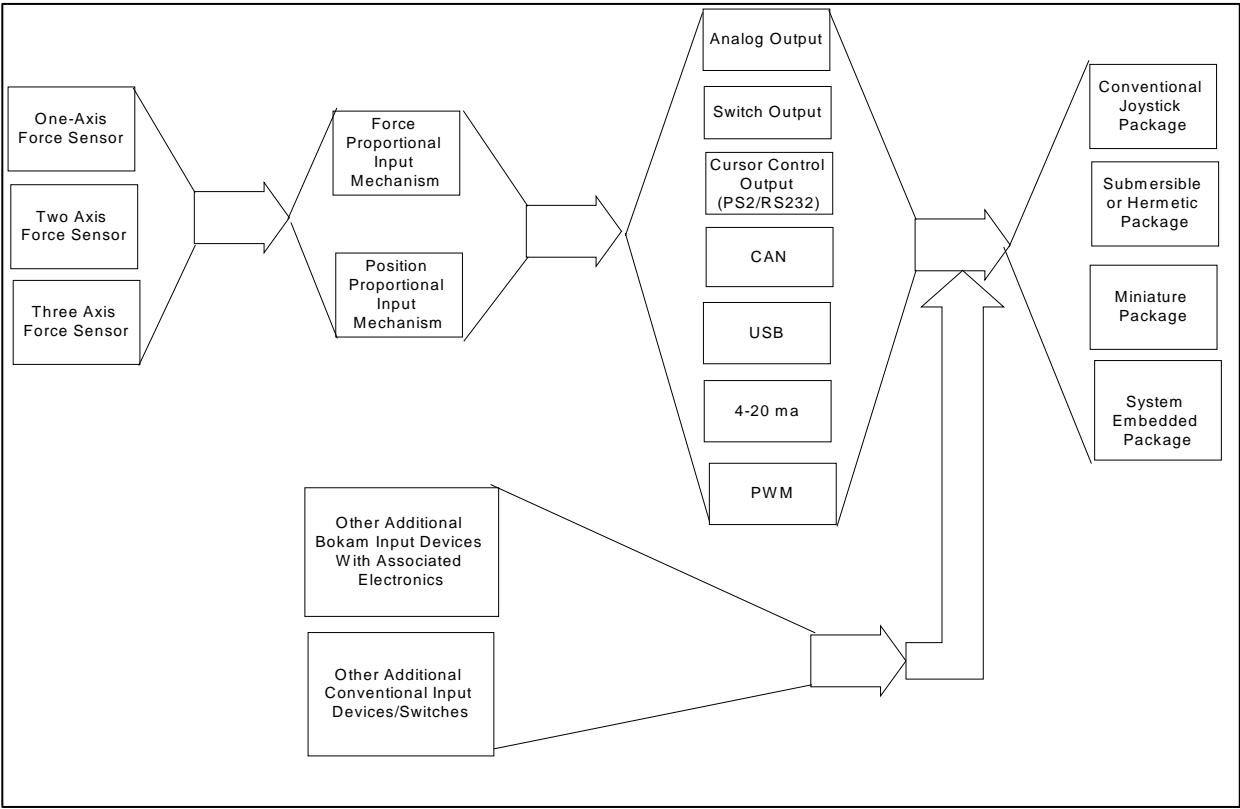


GADOL SERIES POSITION AND/OR FORCE PROPORTIONAL JOYSTICKS

Because the basis of these position proportional devices utilized the same sensor configurations as their force proportional counterparts the devices could be easily hermetically sealed. With the addition watertight connectors on the outputs of the joystick the entire assembly could not be submerged. This meant position proportional devices could now be used in applications where they could easily become submerged in water or any other corrosive substance.

The Gadol sensor contains monolithic solid steel sensor diaphragm that separates the moving or input section of the joystick from the electronic compartment. With all active electrical elements on the underside of the sensing element this arrangement means that the electronic compartment can be hermetically sealed and watertight. The enclosure of the signal conditioning electronics in the modular height adjustable compartment also means that the unit is naturally not susceptible to EMI/RFI.

The electronic compartment can vary in height depending on the number of signal conditioners required. Additional signal conditioners are added to the compartment to work with secondary input devices located on the grip assembly.



INPUT DEVICE BUILDING BLOCKS