Development of the IBM Keyboard F

Abstract: The development history that led to the IBM Keyboard F is chronicled. Keyboard specifications are established. Development motivation and development methodology that was used at each design iteration are described.

Dick Harris

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Introduction

This paper describes the development process that led to the success of Keyboard F. Specifications for a good keyboard are described in some detail to assist others as they think about future keyboard designs. The motivation behind the process was key to the creation of ideas and concepts that led to many unexpected, favorable results in the design. The development method that was used is described recognizing that other methods might deliver similar results. This motivation and method was applied to each concept step leading to Keyboard F.

After reading this paper, it is hoped that you have a better understanding of the characteristics of a good keyboard, and you are better equipped to make your ideas a reality.

This story begins in the year 1965. IBM announced and staffed a new site at the Research Triangle near Raleigh, North Carolina. Part of that site was a small development team that I joined right out of college. Our mission was to develop a full function keyboard that could communicate electronically with the varying computer systems IBM was planning. The inefficiencies of having each system develop its own keyboard had become obvious to the corporation. So the team got to work to develop a keyboard that was easy to use, had a mechanism that was scalable and offered a customizable interface.

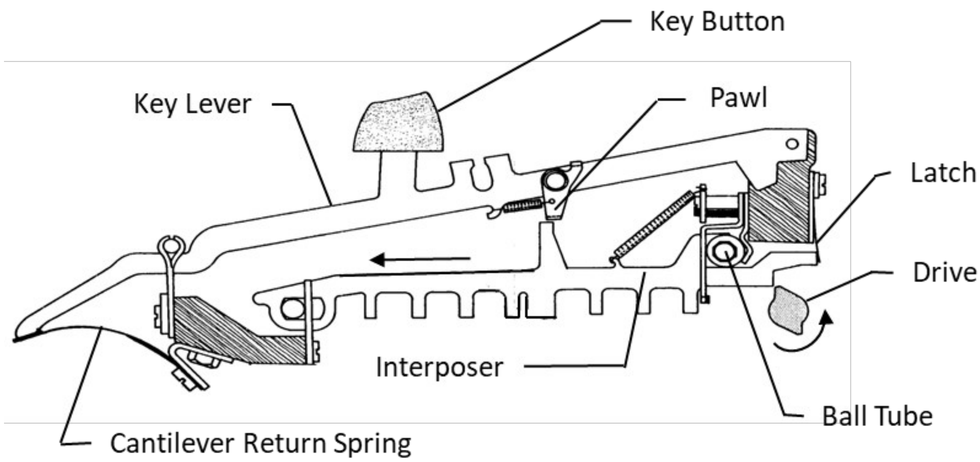
Analysis of Selectric Features

At the time, the best keyboard was used on the Selectric Typewriter. Fortunately, this was an IBM product which had set a standard that deserved to be replicated. This was a complicated mechanism that was highly integrated into the printing function of the typewriter. There was a mechanical decoding system already in the typewriter, but it did not offer the 8 bits required for ASCI or other common communication codes.

The task became one of locating a place for a switch for each key and to remove as many parts as possible without disturbing the touch and operation of the keyboard. It was decided to integrate a row of membrane switches beneath the interposer latch (See Figure 1) so that the switch would close when the interposer was actuated. A solenoid driven bail replaced the Drive to reset the interposer. This keyboard is described in patent US 3,694,606. It was tested and released, but it was an expensive solution that revealed the need for a lower cost keyboard. Any new keyboard would have to emulate all the necessary features of the Selectric mechanism. This led to a thorough analysis of the Selectric Keyboard.

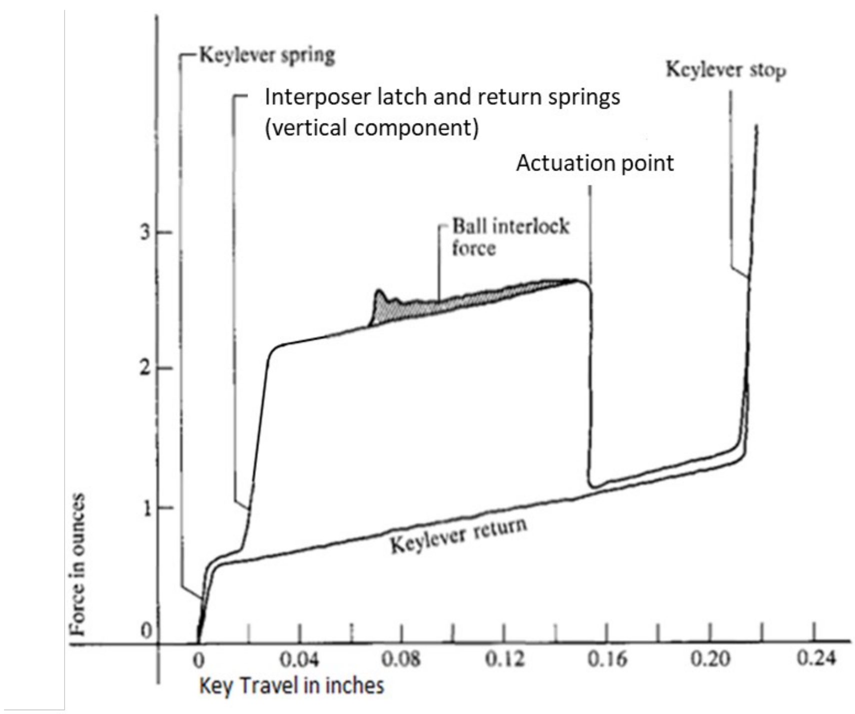
Figure 1 shows a side view of the Selectric Keyboard and Figure 2 is a force-displacement curve (Touch Curve) of the forces to depress the key button and the forces present as the key button is restored to its initial position. The following is a description of functions encountered as the key button is depressed.

Selectric Images



IBM Selectric Keyboard Mechanism

Figure 1



Selectric Key Button Force/Travel Characteristics

Figure 2

Pretravel

When about a half ounce (14 grams) force in applied to the key button, (See Figure 1 and 2) the Key Lever begins to rotate counter-clockwise around a pivot at its right extreme until the Pawl engages the Interposer. This force is resisted by the Cantilever Return Spring. Pretravel ends after about 0.02 inches (0.5 mm) of key travel.

Pretravel allows an operator to depress the key button slightly without effecting the rest of the mechanism. This action can provide confidence that one's finger is correctly positioned, that the mechanism is ready to be operated and offers an opportunity for the operator to stop the key depressing if they realize an error is about to be made.

Actuation Key Travel

Actuation Key Travel begins at the end of pretravel and requires about 2.3 ounces (65 grams) of force and 0.03 inches (0.76 mm) of key travel. The Interposer, driven by the Pawl, begins to rotate around a pivot near its left end, part of the interposer on the right end engages the Ball Tube (discussed later) and the right end of the Interposer moves downward so the Latch spring snaps to maintain a position to be driven to the left and reset by the Drive.

Each Interposer has a unique set of teeth on its bottom edge representing the code for the desired character. Nearly simultaneously with the latch spring snap, a cycle clutch is activated which initiates the Drive to reset the interposer to a position in front of the Pawl and the desired character is subsequently printed. During Actuation Key Travel, key force is resisted by the Cantilever Return Spring, the Interposer return spring and a slight contribution from the Ball Tube. Actuation Key Travel ends at about 0.15 inches (3.8 mm) of key travel and about 2.5 ounces (71 grams) of key force. At the Actuation point the key force suddenly drops to 1 ounce (28 grams).

Tactile Feedback

Actuation Key Travel provides an opportunity for the operator to abort the character selection and also allows the keyboard to ensure that it is ready to accept the character selection. The operator is able to stop the key travel at any point prior to actuation, and the mechanism will return to a ready state that allows for another key to be pressed. The sudden reduction in key force at the Actuation Point is a tactile event providing positive feedback that the key operation has been completed successfully.

Audible Feedback

The sound of the Interposer reset and printing action combine to provide an audible sound indicating successful key actuation.

Single Key Entry

During Actuation Key Travel, the Interposer enters the Ball Tube which consists of ball bearings of diameter equal to the lateral interposer spacing. The balls, inside a slotted tube and with the total of space between the balls equal to the thickness of the Interposer, ensure that only one Interposer can enter the Ball Tube at a time. So, only one Key Button can be actuated at a time.

Overtravel

Overtravel begins at the end of Actuation Key Travel and ends at about 0.21 inches (5.3 mm) of Key Travel when the Key Lever engages the Keylever stop. Overtravel ensures that Actuation occurs during key travel and not at its end. There seems to be a certain satisfaction when the Actuation point occurs during the total key travel as opposed to being at or near the end. Overtravel is about 1/3 of total key travel.

Key Lever Return – nKey Rollover

Key Lever Return begins with the Key Lever fully depressed and against the Key Lever stop. The Interposer has been reset, is free of the Ball Tube and is in front of the Pawl. The only force resisting key force is the Cantilever Return Spring. Reducing the key force allows the Key Lever to return to its initial position. Slightly before reaching the initial position the Pawl snaps to a position to engage the interposer in a future actuation.

Since the Interposer fully restores at the end of Actuation Key Travel with the key fully depressed, subsequent keys can be actuated without the return of the Key Lever. Therefore, every key can be actuated without any Key Lever being returned. This is nKey Rollover.

Unambiguous Actuation

Since Tactile Feedback, Audible Feedback and the initiation of printing occur simultaneously at the Actuation point, there are no false signals. A character always follows feedback and never before. Also, one and only one character is printed during a normal key depression.

Requirements for a New Keyboard

At this point the objective was to establish a specification that described a keyboard that emulated every essential Selectric feature, was easily configurable, and much less expensive to manufacture than the modified Selectric keyboard.

With a modular, manually powered design in mind, each feature of the Selectric was studied to determine if it could be eliminated or implemented in a more cost effective way. Next each characteristic of the Selectric was reviewed.

Pretravel

Pretravel was determined to be a feature with minimal value, but desirable if it could be implemented economically.

Note: Pretravel seemed to possibly impose additional parts and complexity to a modular design where pennies added to a key module quickly become dollars for the keyboard. Later tests showed that it offered no benefit to speed, error rate and usability, and the pretravel requirement was eliminated from future designs.

Key Force/Travel

Actuation key force target – around 50 to 80 grams (1.8 – 2.8 ounces) force.

Total key travel target – 0.150 to 0.180 inches (3.8 – 4.6 mm).

Overtravel

Overtravel – about 1/3 total key travel.

Key Return – nKey Rollover

Key return characteristic was assumed to have little effect on performance as long as Unambiguous Actuation was maintained. Selectric has no feedback during key return.

nKey Rollover was highly desired; however, 2 or 3 key rollover could be a reasonable compromise.

Unambiguous Actuation

Unambiguous Actuation was determined to be mandatory.

Note: Any mechanism that uses key force to directly actuate a switch should ensure that the operator cannot apply a force that fluctuates around the closure force of the switch. This could cause multiple entries of a character. Hysteresis at the actuation point (once closed the switch requires significantly less key travel to open the switch) is one way to prevent multiple entries.

Key Stem Guides

The Selectric has pivoting Key Levers and is virtually immune to key binding.

Note: A modular design would probably have sliding bearings that must be able to resist binding caused by oblique forces and wide key buttons. Parameters reducing key binding are low coefficient of friction at the bearings and large vertical distance between bearings.

Key Module Life

Life requirement of the most used character was determined to be 20 million key strokes.

Note: Manufacturing and assembly/service costs are less when there is only one design for the key mechanism.

Here's a calculation that supports this life requirement.

Calculation assumptions:

- Life of product – 7 years
- Work days per year - 365
- Highest usage customer – 3 shifts a day and 7 hours continuous operation per shift
- Continuous keying rate – 50 characters per minute.
- Letter "E" is the highest used character at 12.7%

Life = 7 yrs. x 365 days/yr. x 3 shifts/day x 7 hrs./shift x 60 min./hr. x 50 ch/min. x 0.127 most used key

= 20,442,555 key strokes life.

Environmental Requirements

IBM had other proprietary requirements like dust tolerance, liquid spills, drop and fragility, etc. that every keyboard design must pass.

Design Motivation

I've found product development to be very rewarding. Most of the projects that I have worked on have been personally fulfilling and a joy to develop. I think the key contributor to this satisfaction has been the underlying motivation. This section will describe what has motivated me throughout my career.

Here are a few words about who I am and what makes me tick. I was born in 1941 during World War ll and grew up in border-line poverty. I began odd jobs at the age of 5 and knew that I wanted to be an engineer at the age of 8. My parents had provided me with a loving, supportive and somewhat strict family. I emerged from childhood with a good work ethic, a desire to make things better, and a sense of who God is. As I grew into a young man, math and science became my favorite subjects – English not so much. I found that I enjoyed school projects that required creativity and the desire to be an engineer increased. I became recognized as a leader and was respected by my peers. I had a growing realization that I was not the same person on the inside as I appeared to be on the outside.

At 16 I attended a Billy Graham event where he told me how I could have a relationship with God, have my sins forgiven and have hope for eternal life. That night I gave my life to Jesus Christ by putting my faith and trust in Him. Life hasn't been the same since. Now all that I do and all that I am is for the glory of God. I was and am far from perfect, but Jesus' life, death on the cross and resurrection changed everything. I am able to live a life full of love, joy, peace and patience, and I have hope for eternity in heaven.

Let me take a moment to explain what giving my life to Jesus Christ means. The Bible teaches that God created us to have a relationship with Him but we all have turned from Him and sinned against Him. Sin means we have done wrong against God. Every one of us is born with this sin condition that has been passed from one generation to the next. The penalty or wages for sin is death. But the gift of God, who is both just and loving at the same time, is eternal life in heaven with God forever. Eternity is too long for us to get it wrong.

When I trusted Christ, I became a new creation (2 Corinthians 5:17), meaning He gave me a new heart. He took my heart that was bent toward self righteousness or selfishness and made it new by His Spirit. It's amazing.

Who is Christ? He is the Son of God given to the world that whoever believes in Him has everlasting life (John 3:16). The Christian Bible is an amazing book. For one thing, it predicted Jesus' birth and death in detail. See https://www.biblestudytools.com/bible-study/topical-studies/times-the-old-testament-predicts-jesus-birth-and-death.html –"11 Old Testament Prophecies of Jesus' Birth and Death". If you know Jesus, rejoice in the hope you have. If you don't know Jesus in a personal relationship, It would be a great joy to help you understand who He is and all that He has done for you to show the depth of His love for you. If you have objections to Christianity, I would love to process those and try to answer any questions you may have. You can contact me at KeyboardBF@gmail.com. Jesus has changed my life and as I get older and closer to the last chapter in my life here on earth, I simply desire to help as many as possible know who He is. Jesus Christ is available to you if you put your trust in Him.

A verse that I've tried to obey for most of my life is Colossians 3:23, 24: "Whatever you do, work heartily, as for the Lord and not for men, knowing that from the Lord you will receive the inheritance as your reward. You are serving the Lord Christ".

My motivation for designing keyboards was to make things better for the glory of the Lord.

Design Methods

My first manager at IBM was a great role model. He appreciated and encouraged innovation and was sensitive to what he called "paralysis of analysis". He wanted due diligence in analysis, but not as a delay for action. He taught me to do the best analysis possible, quickly build models and start testing concepts with the goal to discover mistakes as soon as possible. His insistence on action has served me well. Under his mentorship, I became more innovative and productive. Also, I learned to define a problem in basic and relevant terms.

One goal in development is to deliver a functional product that meets and maintains its product cost target. The method I have used over the years to achieve product cost target is based on the fact that 80% of product cost was fixed by the concept. In other words, only 20% of the product cost can be reduced by materials selection, sourcing and logistics Improvement. So cost effective concepts are key to a successful development project.

Functional Cost Target Method

Since we already had a modified Selectric keyboard to replace, we divided its parts cost and assembly costs into functional groups like key mechanism, frame, electronics and covers, etc. Functional cost targets for the new product were calculated by applying a reduction factor to the cost of each existing functional group. This reduction factor was determined by dividing the total cost of the new product by the total cost of the existing product. Having functional specifications and a cost target for each function, assignments were given to the team, and the team got to work. Some functions were not able to meet their cost targets, and the team had to find other functions that were better candidates for innovation and could beat their cost targets to make up for the shortfall. This method has been successfully applied to many projects.

Tips on Innovation

I have occasionally been asked how I invent, but what they really want to know is, "How can I invent? I'll do my best to answer the latter question.

- **Be intrigued by how things work.** In my case, I've been particularly intrigued by things that produce an unexpected result – things like magnets as they interact with each other, columns that buckle (more about that later) and sliding bearings that suddenly bind and will not move regardless of how much force is applied.
- **Be motivated to solve problems.** As a child I had a desire to make things better. I would often just look for things that needed to be improved. It has been said that "necessity in the mother of invention". I believe discontent is the mother of invention. Something simply doesn't work as well as it could, seems far too complicated or has some other problem that might deserve improvement. The functional cost target method exposed a lot of problems that were the target of focused innovation.

- **Have a well-defined problem.** The problem needs to be defined in terms that are basic and relevant. As the search for a solution is started, I found it helpful to have a vision or a description of the ideal solution that may be impossible but very helpful as alternatives are considered. Significant time should be spent defining the problem. Nothing influences the outcome of a development effort more than the definition of the problem.
- **Be sure that you believe the problem is worth solving.**
- **Be courageous.** Carefully select those to whom you describe your invention. Select those who need to know or who might contribute to the idea. Every person you describe an invention to is an opportunity for you to become discouraged and abandon a great idea. You might be excited by your invention, but some will be terrified by it. Be sure to listen carefully to anyone who expresses concerns and try to understand why they are concerned. If you think their concern can be overcome or has no merit, continue as planned.
- **Be open-handed with your invention.** Suggestions from others can make a good idea even better. If they contribute, be sure to include them on any potential patent applications. Keep your eye on the problem not the invention. When an invention no longer exists, it usually means failure. When the problem no longer exists, it usually means success.
- **Be prepared for the risk involved in developing any unique invention.** There are technical and personal risk and many unknowns in a truly unique idea. Add time and money to the development plan to account for the unexpected. Things never work quite as well as hoped.
- **Be prepared to deal with frustration and disappointment.** As a Christian, I am taught to be submissive to those in authority over me. I report to a higher authority than my management team. More than once, I have been frustrated by decisions made by those to whom I report, but knowing that I'm serving a higher authority has helped me deal with these frustrations.

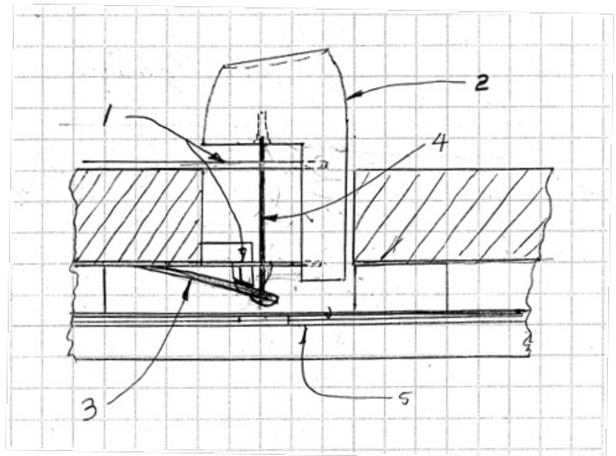
Quest for a Modular Keyboard Design

This section and those that follow describe IBM's keyboard development path that ultimately led to Keyboard F. IBM was not the only company that saw the opportunities for keyboards. There was significant competition for IBM's business, but IBM was dedicated to developing their own keyboard. Our team consisted of capable and competent people who supported each other and shared the common goal of producing a keyboard that would satisfy IBM's future requirements. Much of what follows consists of my contributions which are the only records that I have. Many others in IBM contributed directly with issued patents and indirectly in conversations. Every attempt was made to include them as co-inventors, but many unpublished contributions were made by others who have gone unnoticed. I'm thankful to each of these persons for their influence and for their contributions that made IBM's keyboards among the best. I'm also grateful for the support of our management team.

My first record describing a possible solution for a new keyboard was mid-1968. The problem was defined as: "It is desired to have a simple keyboard configuration that provides good touch, one switch closure and no external drive power." Looking back, I would define the problem as: Design a modular keyboard that meets IBM functional requirements (Emulate the Selectric) and IBM's business requirements (Development budget and product manufacturing cost).

First Keyboard Concept with a Buckling Element

Figure 3 shows a sketch of a concept that was considered. While it did not meet requirements, it is shown here because it is my first concept using a buckling member.



First Buckling Element in a Keyboard Concept
Figure 3

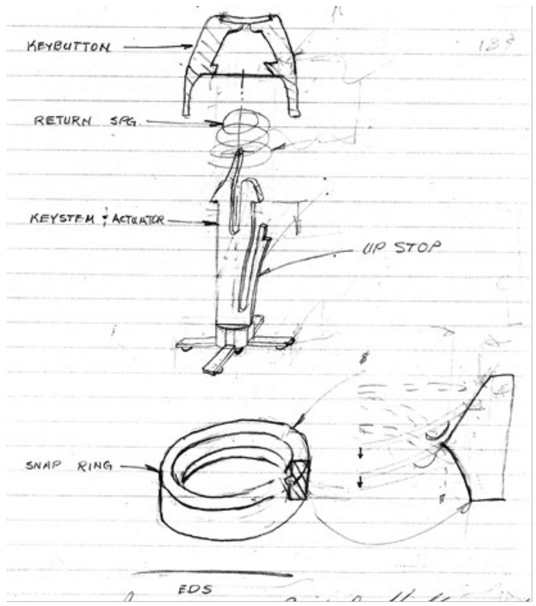
In Figure 3, key button 2 is supported by four thin beams 1 that provide key return force and frictionless guiding of key stem movement. When the key is depressed, Cantilever spring 3 is pressed toward membrane switch 5 by a thin wire column 4 to close switch 5. After the force applied by column 4 exceeds the contact force and column 4 reaches its buckling force, the force on the switch is instantly removed and switch 5 opens allowing other key positions to be actuated. Additional key travel continues to buckle spring 4 so switch 5 does not close again. Release of the key allows the button to return and column 4 to return to its straight state for future actuation.

No functional model was made of this concept because it failed to meet the unambiguous activation requirement. The switch closes before tactile/audible feedback from the buckling wire occurs. This would allow the key to be depressed, the switch to close without any feedback . There are, however, a couple features of this concept that do have merit: frictionless key stem guiding and achieving tactile/audible feedback from a buckling column.

More Momentary Switch Closure Concepts

Another concept dated a year later (1969) is shown in Figure 4. This concept consists of 4 cantilever springs at the bottom of the key stem and a stationary snap ring with geometry that cocks and releases all 4 cantilever springs as the key stem is depressed. Four membrane switches positioned beneath each cantilever spring are momentarily actuated as the cantilever springs strike them. The key stem can remain depressed while other keys are actuated. Release of the key button allows the stem to return. The cantilever springs snap to a position above the snap ring and reset the key module for future actuation.

This concept was never seriously pursued because it appears unreliable because of possible wear on the cantilever spring ends, and a more feasible alternative quickly followed. This is the second concept that utilizes a momentary switch closure to achieve nkey rollover.



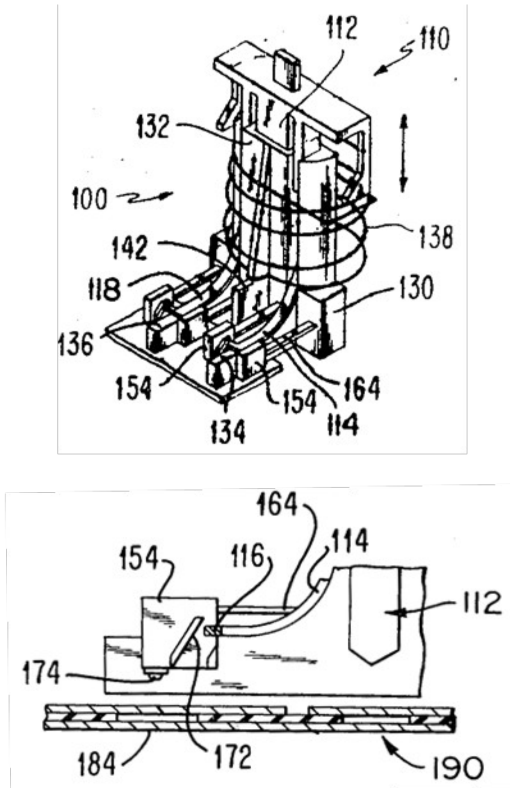
Snap Switch Actuator
Figure 4

Momentary switch closure seemed an idea worth pursuing, and the following Momentary Switch Actuator was considered. Referring to Figure 5, a slidable key stem 112 with two ribbons 114 attached slides in housing 132, and ribbons 114 conform to a ramp detail on the housing. As key stem 112 is depressed, the end of ribbons 114 move in a horizontal direction. A tee like detail 116 at the ends of ribbons 114 engage cams 172 to lift hammers 154. As tee 116 passes under cams 172, hammers 154 snap down towards membrane switch 184 past their neutral position and strike membrane switches 184 to create a momentary switch closure on 4 switches. On return of key stem 112, tees 116 slightly deflect hammers 154 toward switches 184 but not close enough to engage switch 184.

This concept meets all functional requirements: pretravel, unambiguous activation and touch. A working keyboard was planned.

Plastic molds were made for both the key stem and the housings. The membrane switch assemble consisted of copper clad Mylar folded to form both the bottom and top contact planes and related circuitry. This folding gave the project the code name of Origami after the Japanese paper folding art. Ironically, the folded switch assembly became the Achilles heel of the design. We were not able to assemble the switch without getting a short somewhere. There had always been concerns about reliability and the housing with molded in springs for the hammers was complex. The switch shorting problem was enough to justify terminating the project.

I still have a working key module. It's pretty neat. Remember, "**Keep your eye on the problem not the invention.** The search for a solution continued.



US3662138A

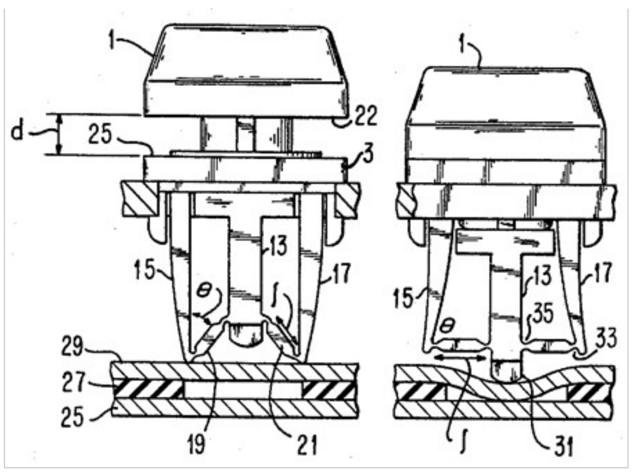
Actuator for momentary closure of an elastic diaphragm switch
Figure 5

Video and Audio available at:

https://youtu.be/dnsUGIqZfvk

Keyboard B – Beam Spring Keyboard

A department nearby had a unique keyboard requirement that they planned to satisfy with a mechanically actuated membrane switch shown in Figure 6. This was a low function, low through-put keyboard. It has a molded, plastic hinge design that provides a decreasing force as the key is depressed to create a detent like touch. Referring to Figure 6, as key 1 is depressed the angle of elements 19 and 21 approach near horizontal which would provide zero force to restore the key, but the key stops against the switch 25,27,29 before horizontal to provide return force.

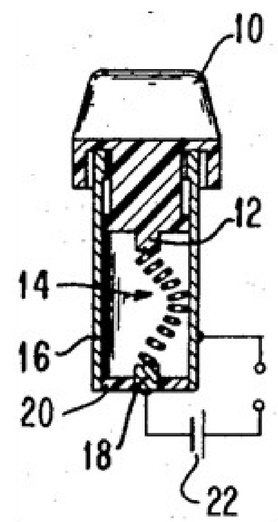


US3668356A

Mechanical key actuator…

Figure 6

I was challenged to design an alternate key mechanism for this system. It turns out that this effort contributed to both the Beam Spring Keyboard and the Buckling Spring Keyboard. After discovering that a long compression spring, compared to its diameter (about 8 to 1), made a pretty good buckling column, the key mechanism shown in Figure 7 was designed and evaluated as a possible solution for this unique keyboard requirement. This was the summer of 1970.



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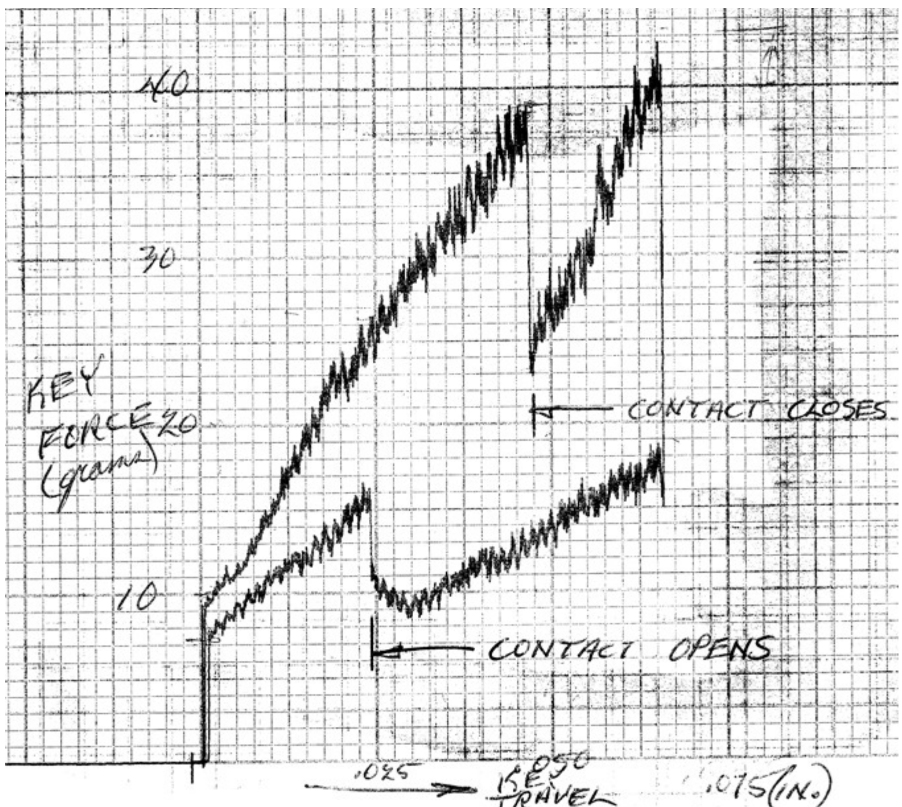
Buckling Spring Contact

Figure 7

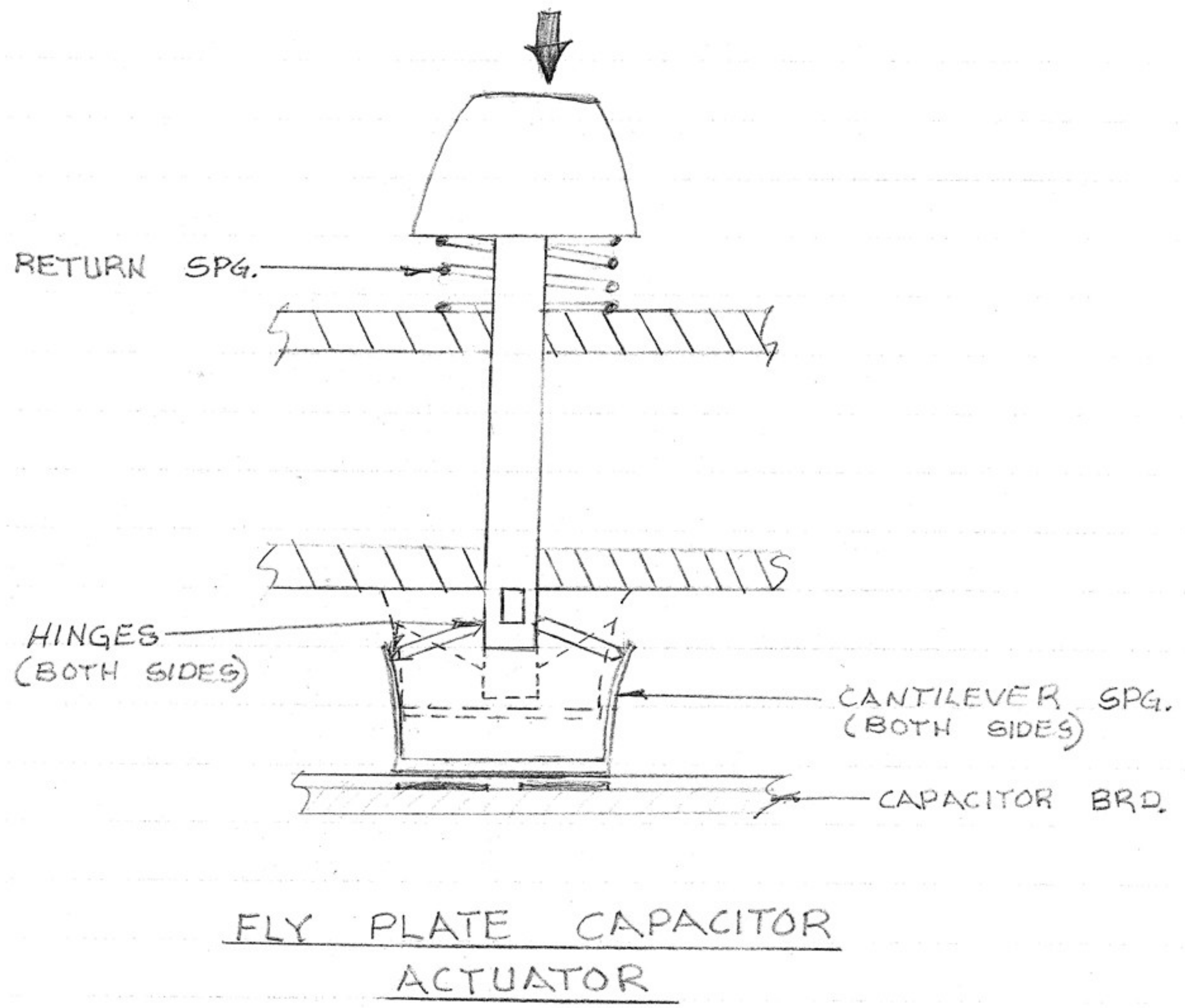
Shown in Figure 7, the mechanism consists of a conductive compressing spring 14 and a conductive cylinder 16 sleeve inside of the housing. As key 10 is depressed spring 14 catastrophically buckles and the lateral extreme of the buckled spring 14 engages cylinder 16 to establish electrical contact. The touch curve, Figure 8, shows that the key must return a significant distance before the contact opens. This hysteresis is a highly desirable feature because it prevents the operator from hovering around the contact actuation point causing multiple switch closures. One disadvantage of this design is that the operator can hover around the contact open point as key 10 is released.

Notice that the key depression part of the touch curve is similar to that of the Selectric Typewriter (Figure 2) if pretravel is removed. This concept was not used on this low function keyboard and the design was patented and shelved. The effort did demonstrate that a desirable touch curve could be provided by a buckling spring. This was the second benefit of this effort. It contributed to Keyboard F about 5 years later.



Buckling Spring Contact Touch Curve
Figure 8

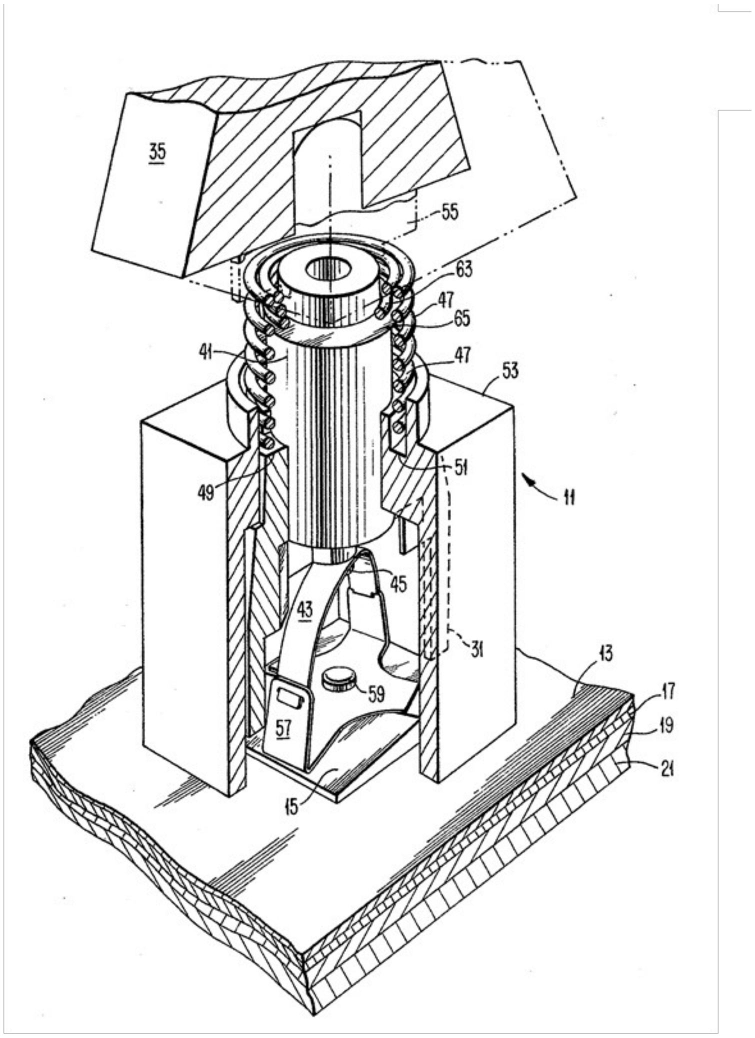
The first benefit came about 6 months later. It is early 1971 and there are several systems in the planning stage that will need a full function keyboard. One that will meet all the Selectric like requirements at a significantly lower cost. Since the demise of Origami, many concepts were explored to meet this requirement, but none seemed to be satisfactory. We now needed to make a decision so more emphasis was applied to the search for a reliable mechanism and a reliable key sensing technology. The electrical team had been working on a capacitive sensing method that should be a very reliable key sensor, but we needed a good key mechanism. Having a few Mechanical Key Actuators (Figure 6) in hand, I started changing things around. Suppose the base (fly plate) that springs 15 and 17 are connected to was free to move vertically about 0.020 inches (0.5 mm), the key stem was attached on the opposite side and the whole key stem assembly was flipped upside-down.



First Sketch - Beam Spring Keyboard
Figure 9

Figure 9 shows an early sketch of this concept. Depressing the key reduces the downward force on the fly plate until the hinged elements are horizontal. Any additional depression applies an upward force driving the fly plate upward against its upper stop. Releasing key force causes the opposite action to occur. The fly plate snaps back against the capacitor board. Notice the similarity to Mechanical Key Actuator in Figure 6. The first benefit from our efforts to satisfy that unique keyboard requirement was Keyboard B.

Figure 10 shows a close representation of the production level Keyboard B. Steel springs replace the plastic springs and plastic hinges to improve reliability. The fly plate is a conductive plastic and key stem and housing materials were selected for good sliding bearing life. Figure 11 shows the Keyboard B touch curve.



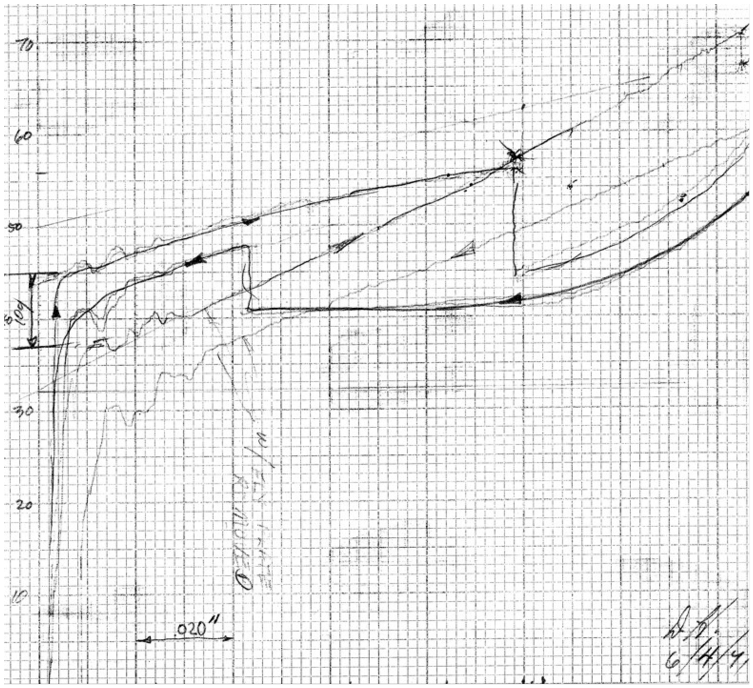
US 4,274,752

Keyboard B – Released Design

Figure 10

Video and Audio available at: Keyboard B

https://youtube.com/shorts/w2ARkp_o_bE



Keyboard B – Touch Curve
Figure 11

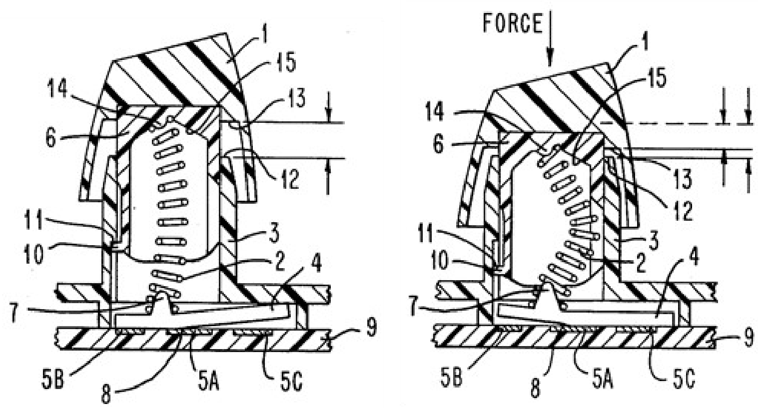
Keyboard F – Buckling Spring Keyboard

Now we spin the clock forward to 1976. Keyboard B has been working well, but competition is starting to get some market traction with their lower height keyboards, and at the same time the Selectric team has modernized their key button shape. A new, lower height keyboard is needed with the new key button shape while maintaining all the functional characteristics of Keyboard B.

Capacitive sensing had proved itself to be very reliable. Cost pressures were always present. A lower cost, low profile key actuator for capacitive sensing was needed. Remembering the Buckling Spring Contact (Figure 7) with its good touch curve and simplicity, I started thinking about ways a buckling spring could actuate our capacitive sensing system. A rocking coupling plate was considered, and it worked very well.

Figure 12 shows the resulting Keyboard F Key Module mechanism. The key module consists of a combined key button/key stem 1, a compression spring 2, a housing 3 and a conductive plastic flipper 4.

Pressing key button 1 compresses spring 2. When the lateral deflection of spring 2 moves slightly to the right of the pivot point 8, flipper 4 rotates suddenly clockwise and spring 2 buckles causing a snapping sound, the capacitance between circuits 5A and 5C to increase and the sensing circuit to signal that the key has been actuated ("Make" in Figure 13). Additional depression of key button 1 does not change the position of flipper 4 or the capacitance. Return of key button 1 maintains "Make" until the lateral position of spring 1 moves slightly to the left of pivot 8 when flipper 4 rotates suddenly counter-clockwise to its initial position and simultaneously spring 1 snaps to more straight state.



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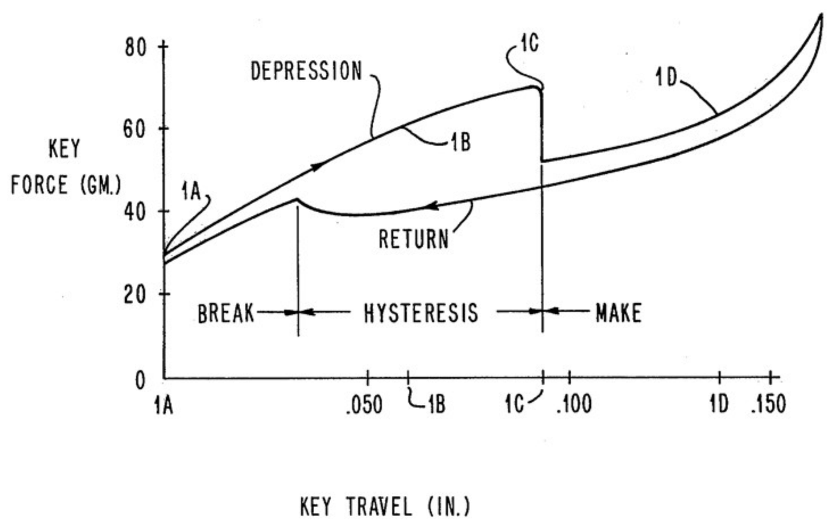
Keyboard F Key Module

Figure 12



US 4,118,611

Keyboard F Touch Curve

Figure 13

Video and Audio available at:

https://youtube.com/shorts/DqgJJsbQ4H4

The buckling spring key module was a significant cost improvement to beam spring key module used in Keyboard B. Several other improvements came together to further reduce cost. One was how nomenclature was applied to the key tops. Double shot molding had previously been used, but it imposed very expensive mold cost, supply chain issues (ordering and delivering individual keys) and assembly complexity. A subliming dye process was developed so that blank key buttons could be assembled on the key board. The characters were printed on a sheet of paper and heat-transferred to the blank key buttons already assembled into the keyboard. Additional cost was saved by curving the keyboard base so that each key could have the same shape and still replicate the new Selectric key top profile making the operators finger reach from row to row nearly the same. Reduced key module part count (from 9 parts to 4 parts), the same key module part number in all standard key positions and subliming dye nomenclature combined to meet the cost target.

Conclusion

Hopefully, the path of innovation leading to Keyboard F has been clear, and you found some things in the Motivation and Method sections that you can use to make your ideas a reality.

It is amazing that the Beam Spring and Buckling Spring Keyboards have the following that they do after over 40 years especially in an age where the half-life of technology is on the order of months. I've enjoyed this trip down memory lane. I hope you have a better understanding of what makes a good keyboard, and you are better equipped for your future.

I struggle with key entry on my phone and Keyboard F is too big to be carried around in my pocket. The keyboard that I am using right now is barely passable. Why don't you fix this?

All to the glory of the Lord