MATERIALS

The following will be a general discussion of materials used in both compression springs as well as stamped cantilever type springs used in battery contact applications. The five basic materials discussed will be music wire, stainless steel, spring brass, phosphor bronze, and beryllium-copper. Each of these materials has many different alloys. Their composition and manufacturing processes differ to a slight degree to yield different performance results. Scientists and engineers have devoted considerable time developing and studying these materials. It would be impossible to discuss them all in detail.

The following pages will provide a brief overview. All five materials can be used to make wound compression springs; however, music wire and other high carbon steels as well as stainless steels are seldom used to make stamped contacts because tooling costs would be too great.

Music Wire

Music wire, commonly called piano wire, is a high carbon cold drawn steel. It is considered to be the best quality steel used for springs. It has high tensile strength, high elastic limit, and can withstand high stresses under repeated loads.
As you might guess from the name, this type of wire was developed for musical string instruments. A thin coat of tin is usually applied to prevent corrosion. This tin coat also provides a good base to further electroplate if desired.

Music wire is best used for smaller springs.
It comes in wire sizes from .004 inches to .125 inches in increments of .001 of an inch. Wire is drawn in many sizes, which allows a designer more options in spring design. Temperatures over 1210˚C (2500˚F) can cause the spring to relax, depending upon the loading. For example: if a spring is loaded to 90,000 PSI 1210˚C (2500˚F), it can cause a 5% drop in spring force. Manufacturers can provide data to aid designers in this area.

Most music wire is made from .8 to .9% carbon. Music wire also contains manganese, silicon, phosphorus, and sulphur. Each manufacturer has its own procedure and chemical composition, which can affect the outcome of the finished product. Wire is drawn through multiple dies to form and harden the wire. This process cold works the wire. The cold work is what produces the tensile strength of the wire. So each batch of wire will have slightly different mechanical properties. The purchaser must test each batch to make sure it has the right properties.

The elastic limit of music wire is usually 65 to 75% in tension and 45 to 65% in torsion. The electrical conductivity is between 8 to 12% of copper. The conductivity can be enhanced considerably through plating. The modulus of elasticity of wire is affected by the diameter it is drawn to. It can vary from 30 million PSI for small wires to 28 million PSI in larger wires. In torsion it can vary from 12 million to 11.5 million PSI. Heat treatment can be used to reduce stresses built up in winding.

Stainless Steel

Stainless steel is very similar to other steels except it contains chromium, from 12 to 20%. It may also contain nickel up to 10%. Chromium and nickel make steel corrosion resistant. Passivating is also a process used to enhance the anti-corrosiveness of stainless steel. Stainless steel is commonly used for springs that will be exposed to environments that are corrosive in nature.

The American Iron Steel Institute has set standards for different grades of stainless steel and designated type numbers so they can be easily specified. They are called the 300 and 400 series. The 300 series contains chromium and nickel at percentages of 18 and 8 respectively. Heat-treating can not harden these types. They are hardened from cold working. Steels can be ordered 1/4, 1/2, 3/4, and full hard. The modulus of elasticity of stainless steel can vary from 28 million to 30 million PSI. Tensile strength can vary from 100,000 to 220,000 PSI. Most manufacturers can provide data on each grade they manufacture.

Brass

Brass is an alloy of copper and zinc. However the word brass is a generalisation because many things can be added to brass to achieve different types of mechanical and electronic properties. There are many different types of brass and manufacturers go to great effort not to reveal the exact compositions. Tin, lead, aluminum, silicon, iron, phosphorus, nickel, beryllium, manganese, chromium, antimony, tellurium, and selenium can be added in various amounts to get different properties. Copper base alloys have excellent resistance to corrosion. Brass is hardened through working the material. It can be bought in the form of wire rods, sheets and coils. Brass can also be bought in 1/4, 1/2, 3/4, and full hardness. Most brass can be welded, soldered, and plated. It is easily formed, bent and cut. Stamping is a common method used to make parts out of brass.

Spring Brass

Spring brass is usually defined as 70% copper and 30% zinc. It is the cheapest of the brasses and used in applications where cost is a factor. It can be easily formed and drawn. It can only be hardened by work hardening. It is good in applications of low stress and low fatigue. It should not be used in applications over 790˚C (1750˚F.) The modulus in tension is around 15 million PSI and in torsion is 5 million PSI. Tensile strength can vary between 70 thousand and 95 thousand PSI depending upon hardness.

Phosphor Bronze

Phosphor bronze is a copper alloy with little or no zinc but possesses 4 to 10% tin and some phosphorus. It is corrosion resistant. It has better mechanical and electrical properties than spring brass. It has a higher cost but also has a higher modulus at 16 to 17 million PSI for tension. It may be stressed 30 to 50% higher and offers higher fatigue life. It is best not to exceed 1070˚C (2250˚F.) This material is the most extensively used stamped spring material due to its cost and performance.

Beryllium-Copper

This material is made out of 98% copper and 2% beryllium. Unlike other copper alloys it can be heat treated for hardness. Its forming properties are excellent. There is no difference in its mechanical properties based on cold rolling directions unlike the other copper alloys. Its electrical conductivity is twice that of phosphor bronze. It can withstand high stress and has long fatigue life. Its modulous tension is between 17 million and 20 million PSI. It can also be used in temperatures up to 149˚C (300˚F). This material is used to make high quality stamped electronic contacts. It also has the highest cost of all the copper alloys.

Materials chart

	Composition	Tensile Modulus x 10^6 psi	Tensile Strength x 10^3 psi	Torsional Modulus x 10^6 psi	Operating Temperature degrees ˚F	Conductivity IACS	Rockwell Hardness
Music Wire	99% iron 1% carbon small amounts other elements	28 - 30	230 - 399	11.5 - 12	250	8 - 12	C41 - 60
Stainless Steel	12-20% Cr 14-18% Ni	28 - 30	100 - 335	10 - 12	288 - 343	8 - 12	C35 - 57
Spring Brass	70% Cu 30% Zn	15 - 16	70 - 95	5 - 6	180	50 - 100	C25 - 30
Phosphor Bronze	94-96% Cu 4-6% Tn some Zn	15 - 16	95 - 110	NA	200	30 - 75	B94 - 98
Beryllium Copper	98% Cu 2% Be	17 - 20	180 - 200	NA	400	15 - 60	C39

Contact performance is based on many factors and conditions. Contact force, the area of contact and the quality of contact is a large factor. The base material, its conductivity and the type of plating materials used for both of the mating surfaces have a large effect on the performance of the contact. The effects of corrosion due to atmospheric conditions and other corrosive conditions can severely deteriorate contact performance, as can oxide build up on contact surfaces. Contact performance is also influenced by the shape of the contact mating surfaces and how they interconnect.

Scientists have spent considerable time studying and documenting this subject. An excellent reference guide on this subject is Electrical Contacts Principle and Applications edited by Paul Slade and published by Marcel Decker. This text explores the above subjects in great detail.

Contact Force and Pressure

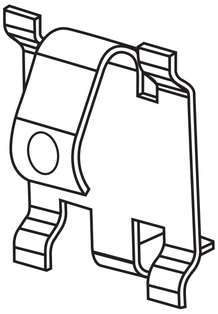
Each electrical signal has a minimum contact force associated with it. Pressure is defined as the force per square inch. Each interconnection has an area of contact that the electrical signal passes through. This area is dictated by the shape of the interconnections and the roughness of the plated or non-plated surfaces. Even though a contact surface may visually appear smooth, on a microscopic level the surface may be very rough. This can cause point contacts in the contact area.

If the contact force is not high enough this point contact could produce high contact resistance and arching. Arching can then further deteriorate the contact surface, which can cause pitting, and further corrosion. Arching also produces oxides, which can also increase contact resistance. Raising the contact force can cause more of these high points to make better contact. Adequate contact force can flatten out these contact points and lower the contact resistance.

Dimple Features in Stamped Contacts

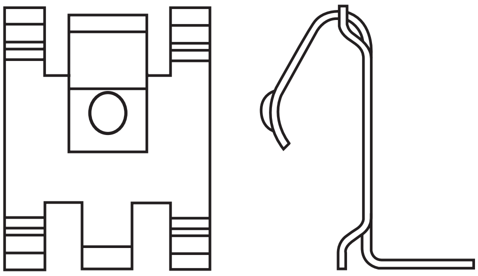
Circular dimple type contact areas are usually good practice to enhance contact pressure. With stamped contacts a circular dimple can easily be added during the stamping process. The size and curvature will vary with each application. The effectiveness of the dimple used must be tested and modified to yield the desired results for each unique application. If the dimple is too small and too sharp the dimple could score the matting surface. If the dimple is too big its effect will be minimal.

Fig-1



These drawings show a typical stamped contact with a dimple type feature to optimise contact pressure.

Fig-2



Designing a wiping action into the mating condition can also enhance contact pressure. The wiping action tends to flatten out these high spots in the mating surfaces. The contact force must be kept to safe levels such that the wiping action does not erode the plating if plating is used. Curved cantilever beams lend themselves perfectly for wiping actions. As the contact is deflected the contact point usually shifts slightly which causes the wiping action on the mating surface. Wiping actions can also wipe away oxides that can form on contact surfaces. These oxides are caused by reactions between the surface material and gasses in the atmosphere. The presence of oxides can act as an insulator that raises the contact resistance. Over a period of time oxides can completely block the electrical signal. Helical springs do not lend themselves to creating dimple features like stamped contacts. Creating a wiping action with a helical spring is also not easy.

Base Material and Conductivity

Conductivity is the ease at which an electrical signal can flow. Copper has the highest known conductivity. Electrical conductivity is related closely to thermal conductivity. So a material that is electrically conductive is usually thermally conductive. Electrical conductivity is expressed as a percentage of the International Annealed Copper Standard (%IACS) measured at 20°C for material in annealed temper. Pure copper has an electrical conductivity of 101 IACS. As elements are added to copper the conductivity decreases, but the alloys created have superior mechanical properties. The conductivity of a material is usually inversely related to the mechanical properties of the material. So, the designer must trade off between conductivity and mechanical performance. The conductivity of copper alloys can vary between 5 and 101 IACS depending upon which alloy is used.

Fig-3

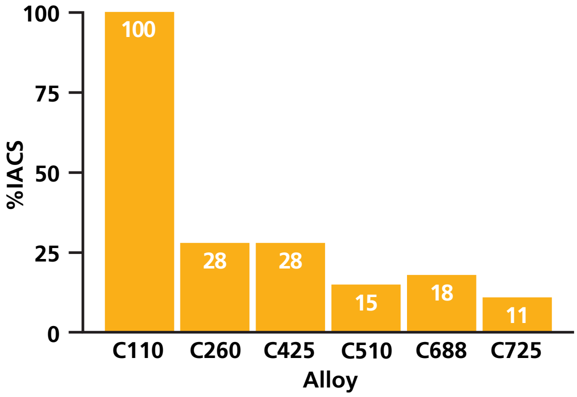


Figure 3 displays the relationship between different copper alloys and their conductivity. The table shown in Fig-4 (overleaf) also shows the strength of copper alloys. If you compare this data you will observe how the conductivity decreases as the strength increases. This is also true for other materials such as steel. This information was taken from an Olin Brass materials guide.

Fig-4

Strength Comparison

	C110	C260	C425	C510	C688	C725
Temper	T.S. (ksl)					
Half Hard	37-46	57-67	57-69	58-73	97-112	65-80
Hard	43-52	71-81	70-82	76-91	106-120	75-90
Spring	50-58	91-100	84-94	95-110	123-133	85-100
Temper	Y.S. (ksl)					
Half Hard	30-44	42-60	51-66	47-68	82-102	59-78
Hard	41-50	67-78	66-79	74-88	95-108	73-88
Spring	48-57	82-91	81-89	92-108	111-117	83-97

The conductivity of most steels are between 10 and 15 IACS. The conductivity of gold is 77 and silver is 100 IACS. Gold and silver have excellent conductivity and that is why they are used for plating. However these elements are very soft so they are usually alloyed with other materials, reducing their conductivity but raising their resistance to wear.

Plating

Plating of base spring and contact materials is used to enhance the conductivity of base materials and also coat the base material to protect from corrosion. There are two main ways to add precious metal to a base material, plating and cladding. Inlaying or cladding a plating material into a base material can be done by skiving a groove into the substrate material into which a strip of plating material is placed. Rolling the material to the desired thickness also bonds the material together. Inlaying can also be done for wire by pressing the substrate material in the form of rods into tubes of the plating material. The composite is drawn through dies to the desired wire diameter. Inlayed materials are very expensive, but remove the need to plate after the spring or contact is manufactured. It is similar to paying for the plating up front in the stock material. Common cladding materials are pure Gold, 75Au25Ag, 80Pd20Ni, 60Pd40Ag, 69Au25Ag6Pt and Palladium. Plating after the contact or spring has been formed can be done by electrolytic and non-electric methods. The following materials can be used for plating; Tin and tin lead alloys, hard golds, gold flash, silver, silver gold alloys, nickel and nickel alloys. Most of these platings are added in very thin films between 1um to 5um.

Hard gold is the best finish for most contact applications. Noble metals are less prone to film build-up. Gold is subject to pore corrosion. Because of the high conductivity, it can be used to drop the contact force needed to transmit the signal desired.

Palladium and palladium-nickel alloys are used in place of gold where cost is a concern. Palladium is about 1/3 to half the cost of gold. It however can develop films in polluted environments.

Tin and tin lead alloys are relatively inexpensive but due to softness are not durable. Tin can also grow what is known as tin whiskers and fretting corrosion.

Nickel is also an inexpensive material but develops thick oxide coatings which must be broken by high contact force and whipping action of the contact. Since nickel is used to plate most batteries nickel is an obvious choice for the mating contact. Using the same material removes the possibility of galvanic corrosion and wear challenges, plus using the same plating on mating surfaces creates similar wear. Plating hardness also plays a roll in picking adequate plating. High conductivity is desired but high conductivity is usually related to softness, which in turn means low wear resistance. Again we see there is a trade off between conductivity and hardness. The table opposite (Fig-5) shows relative hardness values for electro-deposited plating alloys.

Fig-5

Tin-Lead Alloys	7-12	
Tin	8-35	
Gold, Pure	40-90	
Silver	40-185	
Hard Gold	160-220	
Palladium	200-300	
80Pd20Ni	355-550	
Nickel	800-1000	
Ruthenium	800-1000	

Conclusion:

A designer is challenged with choosing a base material that can yield the necessary mechanical properties required for contact force whilst being aware of its conductivity. Conductivity can then be enhanced by plating the base material, and dimple features introduced to improve contact pressure, lowering contact resistance. Plating can enhance the interconnection, however it can introduce added cost, oxidation and corrosion problems. Each interconnection problem is different and must be treated so.

Cost is a combination of many elements: base materials, tooling used to manufacture the base material into the spring, manufacturing time needed or machine running time, secondary operations, plating and volume - all need to be addressed before deciding on a spring design.

Base Material

Base material in the form of drawn wire for wound springs or rolled sheets for stamped contacts are affected daily by the cost of fair market value of the base materials, especially when you are dealing with the more precious type metals. Markets control these metals just as the prices of stocks are controlled by the stock market. Supply and demand is the basic rule. The more exotic a material, the higher the cost. Alloys including many elements usually require more sophisticated processing with higher quality control. These alloys usually have higher mechanical properties, so there is a direct relationship between performance and price.
This performance could be strength, corrosion resistance, resistance to strength relaxation and so on. The more a material is worked the more it costs; for example, full hard material is more expensive than half-hard. The thickness of the stock material and the tolerance required by the designer can affect the cost. A tighter tolerance can drive up cost. A tolerance of (+) or (-) .0005 will have a greater cost than (+) or (-) .001. Cladding a material or adding an inlay into a base material will increase material cost considerably, but the cost can be balanced out if plating is not used. Paying up front for inlaying can sometimes provide a cost saving, it can however increase your manufacturing costs. Manufacturing with inlaying and cladding can be tricky and require greater inspection and quality control. Scrapping a lot of contacts made with inlayed material is more expensive than scrapping a lot of non-inlayed material. It is safer to stamp or wind than inspect and then plate, since a dimensional mistake can be detected prior to plating.

Tooling and Manufacturing

Tooling for wound springs includes a spring winding machine and the arbor needed to wind the spring. The daily volume needed dictates how many machines are needed or how many shifts need to run. If it takes 10 seconds to wind a spring then 6 springs can be wound per minute and 360 springs per hour. Calculations like these must be made to determine the number of machines or number of shifts. The number of springs made per hour dictates the piece part price because there is a machine time cost per hour. This cost is based on the people needed to set up the machine, check the finished product and maintain the machine. For most requirements, contracting spring winding to spring manufacturing companies is the best option, eliminating the need to purchase machines and train people to set them up, run them and maintain them. It is also easier to design a spring in such a way that it may be bought off the shelf. There are many companies that make and stock certain sizes that are commonly used for known applications, lowering the cost dramatically.

Tooling for stamped contacts is more complicated. This requires a stamping press as well as the design and manufacture of a stamping tool. Further costs include the maintenance of that tool and the set up cost to install the tool in the press when parts are needed. Tools can be designed with multiple capacity. They could be designed with one contact per strip or as many as four contacts per strip. A one capacity tool is less expensive than a two or four capacity tool because each stamping station must be duplicated so many times. Each tool has blanking stations and stamping stations. The strip is fed into the tool and is carried by carriers through the die. Each time the die opens and closes the strip moves to a different station. The blanking stations remove material not needed in the part. The forming stations place the bends and forms needed. There is a tool made for each blank and form. Each blank and forming tool must be made and heat-treated. The harder the base material the more expensive the tool will be because it will require a more sophisticated tool steel and heat treating to stand up to the work required. The larger the number of forms and blanks and the more complicated each form and blank is, the more expensive the tool will be. The tolerance associated with each blank and form also increases the cost. The speed of the die and the number of stations dictate the time it takes to make each part. The more parts that can be made per hour the lower the cost. Once the tool is paid for, costs will include the machine time, the material needed and the maintenance of the tool. This is usually included in the piece part price. Just as with spring winding, most of the time it is better to farm out this work to a stamping house because they have the expertise and the presses. Once the design is complete a stamping house can quote the price of the tool and a piece part price for the part.

Plating

Plating can be done in different ways. Barrel or batch plating can be done with contacts that will not tangle or can be easily untangled. Barrel plating is also used where the whole contact is plated - excellent for wound springs. A de-tangling feature can be designed into the spring by having some dead coils in the middle. Dipped plating is done when the contacts are still on the stamping strip and they are dipped into the plating and only a selected area is plated. This is commonly done in the electronic connector industry. The contacts are left on the strip. They are made on the strip in the same spacing or pitch that they are assembled into the insulator. After plating they are pressed into the insulator and the strip is broken away.

The cost of plating is dictated by the cost of the precious metal used, the time it takes to plate and the cost of that time. Cost of plating materials such as contact material can vary day to day. The more sophisticated the plating alloy is the higher the cost. The plating demands sometimes require a base coat and a flash coat. This is obviously an added cost. Barrel plating is usually less expensive because it requires less prep time and many parts can be done simultaneously, however it has added cost if the contacts need to be de-tangled. Dip plating uses less plating but requires more handling costs and set up time. This process is very time consuming because there the number of contacts that can be dipped at once is limited, increasing costs further. Again this process is best left to companies that are experts in this area. There are many environmental requirements to deal with if one wishes to do their own plating. Once the plating requirements are known and the spring or contact design is complete a plating company can supply a piece part quote.

Secondary Operations

Secondary operations, aside from plating, can be costly because they usually require handling and fixtures. This should be avoided whenever possible. Each time a human being handles a part it becomes more expensive. Secondary operations can be cutting contact strips into lengths, separating the strip from the contact, or bending contact tails after assembly. For springs, secondary operations could be grinding the ends of springs and welding or soldering elements to the spring.

Volumes

Volumes are the biggest variable in cost. The higher the volume the lower the cost of a part. When prototyping a stamped contact a sample charge could be astronomical compared to the high volume price of the contact. This is because it could take hours of a toolmaker’s time to produce all the blanks and bends necessary to make the contact. Sample charges of wound springs are usually much less. This usually requires a set up charge comparable to a few hours of running time.

The tooling and set up charge is the largest up front cost. The longer a tool is run the smaller the part price becomes because it eliminates the human factor to set the tool up. If a tool can be run without human supervision or with minimal supervision this can also reduce part cost. A spring machine can only produce one spring at a time. To up the capacity, more spring machines must be purchased. A stamping die can be made with one to four part capacities. This cuts the cost dramatically because it is doing the same work and spending the same time to produce more parts. This, however, may require a bigger machine with higher force capacity. It can also require more quality control costs and higher maintenance. Volume needs dictate the part capacity of the tool. It would be more cost effective to build a one-part capacity tool for small volumes; higher volumes would demand higher capacity tooling.

A spring or stamping supplier should not only supply a part price but there should be price breaks based on different levels of volume. The higher the volumes the less the price. The designer should get several quotes from different suppliers and base them not only on price but the quality of the work and the supplier’s reliability to meet deadlines and supply parts that meet specification. The price will increase if the parts have to be scrapped, returned or reworked. Sometimes paying a little more for a part from a more reliable supplier is actually more cost effective.