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REUSABLE TAMPER-INDICATING SECURITY SEAL

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Abstract

A reusable tamper-indicating mechanical security seal for use in safeguarding nuclear material has been developed. The high-security seal displays an unpredictable, randomly selected, five-digit code each time it is used. This five digit code serves the same purpose that the serial number does for conventional non-reusable seals - a unique identifier for each use or application. The newly developed reusable seal is completely enclosed within a seamless, tamper-indicating, plastic jacket. The jacket is designed to reveal any attempts to penetrate, section or to chemically remove and replace with a counterfeit for surreptitious purposes.

1. Introduction

A very strong need exists for an improved high security tamper indicating seal for safeguarding nuclear material. The reusable mechanical seal has the characteristics most often stated as being desirable. The seal is easy to install - no special equipment or tools are needed. It can be used for a wide assortment of applications because a specially designed 1.5mm diameter braided cable is utilized. Most all existing applications which will accept a cable of this diameter can be accommodated without revision. There are no internal or external electrical power requirements. The seal is rugged, lightweight and compact, measuring approximately 4.5cm x 5cm x 1.7cm thick. There are no maintenance requirements. Each time the seal is used, it internally generates an unpredictable, random five digit code which is displayed in a viewing port. The design utilizes many small colored balls located in a mixing drum, out of which five of the balls are randomly withdrawn and fixed in an area outside the drum. The order of the five colored balls becomes the code for that particular use. A single digit is assigned to each of the five colors, hence the code can be read as a five digit number for ease of recording. When the seal is operated the balls isolated in the viewing port are transferred to the mixing drum so that five different balls can be randomly selected for the next application of the seal. The displayed five digit code, in addition to the seal's fixed serial number, becomes a unique identifier for each use of the seal, similar to the serial number used for conventional one-time-used seals.

The reusable seal is completely encased in a 1mm thick, seamless, clear plastic jacket designed to indicate any attempts to compromise its integrity and to verify that it is genuine. It contains images of human faces printed on clear film by the half-tone process, thus it is possible to see through and around the images. All surfaces of the seal, including the area beneath the images of faces, are coated with an array of aluminized small dots ½mm in diameter at a density of 60 dots per cm^2. This density of dots permits a transparency of 82%. A label with the seal's logo and colored ball legend is located about 1mm below the plane of the human faces and array of dots. With this arrangement, an inspector examining the seal can see through the clear plastic of the jacket, can see the images of the human faces, the array of small dots and the seal's label. By slightly rocking the hand held seal from side to side, the parallax between the images (and small dots) to the label located below them is clearly discernible and a positive indication that they are in different planes. Because the images of human faces extend around the seal's edges and because they are in the same plane as the reflective dots, it is virtually impossible to duplicate the images of the faces by photographic means. Furthermore, attempts to photograph the images for counterfeiting purpose would place the seal's label in the same plane as the images and thus the parallax, discussed above, would be lost, indicating a counterfeit. An inspection of the uniform array of reflective dots is very quickly made by viewing each flat surface of the seal with reflected light. Penetration or sectioning of the cocoon surface would be indicated because the uniform order of the dots would be interrupted. No tools or equipment are needed by an inspector to verify the seal's integrity.

A specially multistranded copper and stainless steel braided cable, about 1.5mm in diameter, has been designed for the seal. The spooled cable can be cut to any desired length at the time of installation with an ordinary cutting tool. After the cable is threaded through the item to be sealed, both ends are inserted through the holes provided in the security seal and pulled tight. An allen type wrench is inserted into the seal and rotated 180 degrees to complete the installation. During the first 90 degrees of rotation of the wrench, four prongs, within the seal, penetrate (pierce) both ends of the cable transversely (at its center line) thus securely and positively locking the cable within the seal body. The code is selected and the viewing port is opened during the next 90 degrees of rotation. Thus it is not possible to establish a code and then install the seal.

Design Features

Seal. The seal is approximately 4.5cm wide, 5cm high and 1.7cm thick. Two cable holes are located at the upper portion of the seal and pass through its thickness. These holes are just slightly larger than the diameter of the cable and are tapered to facilitate entry of the cable through the seal. The seal is operated by inserting an allen wrench through the opening in the center of the seal. One complete rotation (360 degrees) of the wrench will cause a full cycle of the seal's operations. There are four separate

operations, each performed by rotating the wrench clockwise 90 degrees. The first quadrant of rotation destroys the displayed code and the balls are returned to the mixing drum. The second quadrant retracts the prongs from the cable, thus allowing the cable to be removed and a new cable to be installed. The third quadrant of rotation causes the four prongs (two for each end) to pierce the cable - transversely through its center line. The fourth quadrant of rotation causes the code to be generated and the view port to be exposed, so that the five balls can be seen. There are a total of 60 colored, 3mm diameter, aluminum balls, twelve each of five different colors in the mixing drum. Because there are five balls and 5 different colors, the possible number of different codes is equal to 5^5 or 3125.

The mixing drum rotates on a shaft within a small clutch which permits the drum to be rotated in only a clockwise direction. A cam-follower arrangement on the rotating drum causes the four cable prongs to translate the distance necessary to penetrate the cable ends perpendicularly at their center lines. A flange on the mixing drum covers the viewing port until after the balls have entered it and are secured. Therefore, it is not possible to see the balls enter the code viewing port and manipulate a preferred arrangement. A section of the same flange has a wedge shape design that removes the balls from the viewing port by positive displacement. A spring plunger type detent is provided so that the "open" and "locked" positions are indicated and held securely.

Cable. The specially designed cable consisting of 16 strands of tin coated copper wire (0.15mm) and 16 strands of stainless steel wire (0.15mm), are braided in a uniform herringbone pattern to permit easy visual inspection of possible tampering. Any disruption of the pattern would be suspect. Two dissimilar metals were selected to foil attempts of heat bonding methods. Any tin removed from the coated copper wire would be visual evidence of possible tampering. The braided cable permits easy cutting of the cable to any desired length and yet prevents unravelling of the many strands so that insertion of the cable ends into their holes can be accomplished without difficulty. All slack in the cable can be removed by simply pulling on both ends of the cable, while moving the seal body toward the item to be sealed.

Tamper Indicating Jacket. The clear tamper indicating epoxy jacket, called a cocoon, is approximately 1mm thick and completely encases the security seal. It is formed in a single casting operation and therefore is free of seams or parting lines. The cocoon provides four types of information to protect the seal from undetected tampering action.

1. That it is genuine; not a counterfeit.
2. That penetration operations, i.e. drilling or piercing have not occurred.
3. That sectioning operations have not occurred.
4. That several seals have not been selectively disassembled and one seal reassembled from the parts for unauthorized use.

As discussed earlier, the cocoon system has three components in addition to the clear epoxy.

1. The completed seal assembly is coated by an aluminum vapor deposition process, after being properly masked, so that all surfaces of the seal are uniformly coated with an array of small dots. Each dot is ½mm in diameter with a density of 60 per cm^2 giving an 82% transparency. Because of the uniform dot pattern it is easy to inspect for discontinuities which would indicate penetrations.
2. Images of human faces are photographically printed on clear thin plastic film by the half-tone process thus, it is possible to see through the images. The film strip is placed around the seal at its mid-point, and over the previously placed small reflective dot array which can be seen underneath. All seals, of a given lot, have identical images and dot patterns. Human faces were selected because it is much easier to commit them to memory than other living or inert objects. Also very small changes can result in changes of the expression in the human face which are more easily observed than images of objects.
3. The seal labels which are bonded to the inside surfaces of the front and back plates of the assembled seal are about 1½mm below the surfaces of the images of human faces and dot pattern. The separation provides the opportunity to observe the parallax between them and thus confirms that they are not on the same plane.

After the seal is assembled and the cocoon applied, an inspector can look through the clear plastic coating of the cocoon, and see the aluminized dot pattern, the images of human faces which extend around the mid-section of the seal and the labels located under the front and back cover plates of clear plastic. The markings on the label are visible through and around the images and dot pattern. The images are easily recognized by an inspector but virtually impossible to duplicate without the master negative because, the faces subtend around the corner edges of the seal, and because the dot pattern is visible through them. The plastic cocoon is formed around the images and dot pattern in its liquid state. Because it is "wet", the dots and images of the faces are transferred to the cocoon. The seal and cocoon are of the same plastic family, therefore, any solvent for one will dissolve the other. The thickness of the jacket surrounding the seal is not constant, so that preferential dissolution is difficult. Thus, intact images and parallax with the seal label confirms that the seal is genuine. A quick inspection of the dot pattern on each surface, greatly enhanced by a reflected light source, confirms that the seal has not been penetrated. The protective cocoon therefore serves as an inexpensive tamper indicating shield which is amenable to quick and easy inspection in the field without special tools or equipment.

2. Status

A prototype of the Tamper Indicating Reusable Security Seal has been made which demonstrates its concept, the mechanical design and tamper indicating features. The seal has not been field tested nor has there been an in-depth evaluation to determine its susceptibility to possible means of defeat, and their possible costs

and time. As stated by many, and certainly true, "the sealed item becomes a part of the total sealed system. Each component: the seal, the cable and the container should be equally difficult to defeat." It appears that the degree of safeguards provided by the reusable Argonne seal and cable is better than that provided by many containers that are in use. The seal design is covered by a U. S. Patent.

3. Statistical Study

To determine if the codes generated by the seal are truly random, a sample of 100 codes were generated. The Chi square (χ^2) method was used to evaluate the data. As indicated below, the results show that the seal does generate codes on a random basis.

Expected results from 100 code samples

1. Each of the five colors is expected in each position of the code (100/5) 20 times for the 100 samples examined.
2. Each color is expected to appear a total of 100 times. One time for each sample.
3. The possible combinations (e.g. one pair, two pair...) are shown in the first column of Table I. Each letter represents any one of the 5 colors. The total number of permutations is given in the second column. The third column gives the multiplicity due to the fact that there are 12 balls of each color. The fourth column is the product of the second and third and is the total number of ways that the corresponding combinations can be made. The fifth column expresses the fourth column as a percent of the total.

TABLE I

Combinations 1	Permutations 2	Multiplicity 3	Total 4	Percent 5
AABCD	1200	228096	273715200	41.76
AABBC	900	209088	188179200	28.71
AAABC	600	190080	114048000	17.40
AAABB	200	174240	34848000	5.32
ABCDE	120	248832	29859840	4.56
AAAAB	100	142560	14256000	2.18
AAAAA	5	95040	475200	0.07
TOTALS	3125		655381440	100.00

Data from 100 Code Samples

Table II shows the number of times that each of the five colors appeared in each of the five positions of the view port for the 100 samples. The expected value for each entry is 100 samples/5 colors = 20; It follows that the expected value for the total number of times a color appears is 100.

TABLE II

Ball Position

Ball Colors	1st	2nd	3rd	4th	5th	TOTALS
A	24	26	20	22	14	106
B	17	13	19	14	25	88
C	26	20	22	19	21	108
D	17	19	16	26	18	96
E	16	22	23	19	22	102
TOTALS	100	100	100	100	100	500

Table III shows the number of times that each of the seven possible combinations occurred and their expected values (from Table I).

TABLE III

	Combinations	Observed	Expected
1	AABCD	39	41.76
2	AABBC	31	28.71
3	AAABC	19	17.40
4	AAABB	4	5.32
5	ABCDE	4	4.56
6	AAAAB	3	2.18
7	AAAAA	0	0.07

Applying the Chi square tests

1. From the 25 values in the colored ball distribution shown in Table II, $\chi^2 = 17.7$. From the Chi square table with 24 degrees of freedom this value would be expected to occur 81.5% of the time for a random system.
2. Using the totals for each color frequency from Table II, $\chi^2 = 2.640$. With 4 degrees of freedom (5 colors - 1) this value would be expected to occur 62.3% of the time.
3. Using the frequency of the different combinations with the expected frequency in Table III, $\chi^2 = 1.287$. With 6 degrees of freedom this value would be expected to occur 97.1% of the time.

It is concluded, therefore, that the reusable mechanical seal generates codes that are random.

4. Field Inspection Procedures

To inspect the reusable seal the following steps are recommended:

A. An overall visual appraisal is made to determine if any obvious unusual conditions exist (e.g. external physical damage - excessive dirt, grease or paint).
B. Check serial number and colored ball code. Compare to record. Inspect view port area of tamper indicating jacket by reflected light on dot pattern and its outer surface area for any possible penetrations and repair.
C. Shake seal, - should be able to hear the colored balls within the seal indicating they are free for mixing and available for code selection.
D. Check to determine that the cable is securely held within the seal. Inspect the back of the seal to determine that the prongs do indeed penetrate the cable.

E. Examine front, back and side images of the faces to determine if correct and that details are discernible and normal. All seals from a given lot have identical images.

F. In conjunction with C above check for parallax between faces and labels by slightly rocking the seal.

G. Check dot pattern on all surfaces for discontinuities. This is most easily done by causing the dots to reflex from a light source.

H. One of the easiest and possibly the best way to inspect an installed seal, is to observe the four phases of operation. Insert wrench, rotate 90 degrees clockwise, observe that code is destroyed, cable still locked in seal. Rotate another 90 degrees - cable should be free Remove seal and cable - inspect total length of cable for damage. Check woven cable pattern for discontinuities, check near the ends of the cable for the two prong holes which should be clearly visible, and that there are not more than two holes at each end. Cut new cable length, install cable, install seal, rotate wrench 90 degrees - cable should be secured, rotate 90 degrees, code should be visible. Record new code in record with seal serial number.

I. If H is not performed. Check cable for obvious damage - paying particular attention at the cable seal interface. Make sure the cable is securely held in the seal by applying a sharp, quick tug on the seal.

5. Production & Cost Estimates

It is anticipated that the seal's plastic parts, including the tamper indicating cocoon, would be manufactured by the injection molding process. Metal parts would be made by high production machines such as the punch press and screw machine. Some parts, such as the clutch, fasteners and colored balls, cable and labels would be purchased. It has been estimated that tooling costs would be approximately $30,000. It is estimated that all components would cost approximately $12.00/seal.

Parts	$12.00
Assembly	7.50
Contingency and packaging	5.50
TOTAL (not including tooling)	$25.00

It is therefore estimated that the seal could be procured for about $50.00 each (1980 dollars) depending upon quantities ordered. Because the seal is reusable, cost per application would be considerably reduced with a high use factor.

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7. References

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Fig. 1 - REUSABLE SECURITY SEAL WITH TAMPER INDICATING COCOON

The seal is shown in the locked position. The five colored code balls can be seen in the view port and the legend for converting the colors to a numberical code. The specially designed braided cable is shown passing through the two holes provided at the top of the seal - The allen wrench opening at the center is used to operate the reusable seal.

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