(12) UK Patent Application (19) GB (11) 2 224 590 (13) A

(43) Date of A publication 09.05.1990

(21) Application No 8825949.4

(22) Date of filing 05.11.1988

(71) Applicant
The Plessey Company plc

(Incorporated in the United Kingdom)

Vicarage Lane, Ilford, Essex IG1 4AQ, United Kingdom

(72) Inventors
Roger William Whatmore

(74) Agent and/or Address for Service
E Pritchard
The Plessey Company plc, Intellectual Property Department, Vicarage Lane, Ilford, Essex, IG1 4AQ, United Kingdom

(51) INT CL[4]
G07D 5/00

(52) UK CL (Edition J)
G4V VPK VP2AX1 VP2A3A VP2A4 VP2A6 VP2A9

(56) Documents cited
None

(58) Field of search
UK CL (Edition J) G4V
INT CL[4] G07D, G07F

(54) **Coin validation apparatus**

(57) A method of validating a coin entering coin validation apparatus, the method comprising the steps of providing a coin chute 2 arranged for directing the entering coin 1 onto a hard striking surface 3, detecting acoustic vibrations 4 emitted by the said coin upon striking said surface, converting said vibrations to corresponding electric signals, processing said signals to measure the intensity of sound emitted in each one of a series of frequency bands, after a predetermined time interval again detecting acoustic vibrations remaining in the coin and making a further measurement of the sound intensity in said frequency bands, comparing the resulting intensity changes with stored spectra representative of a range of standard coins, and indicating which value of coin 1 corresponds to that having entered said apparatus.

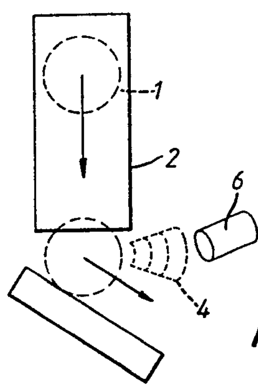

FIG.1.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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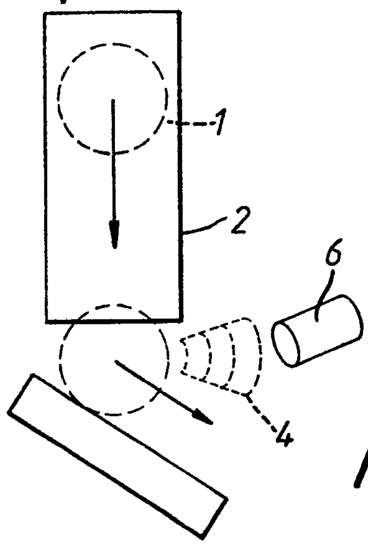


FIG.1.

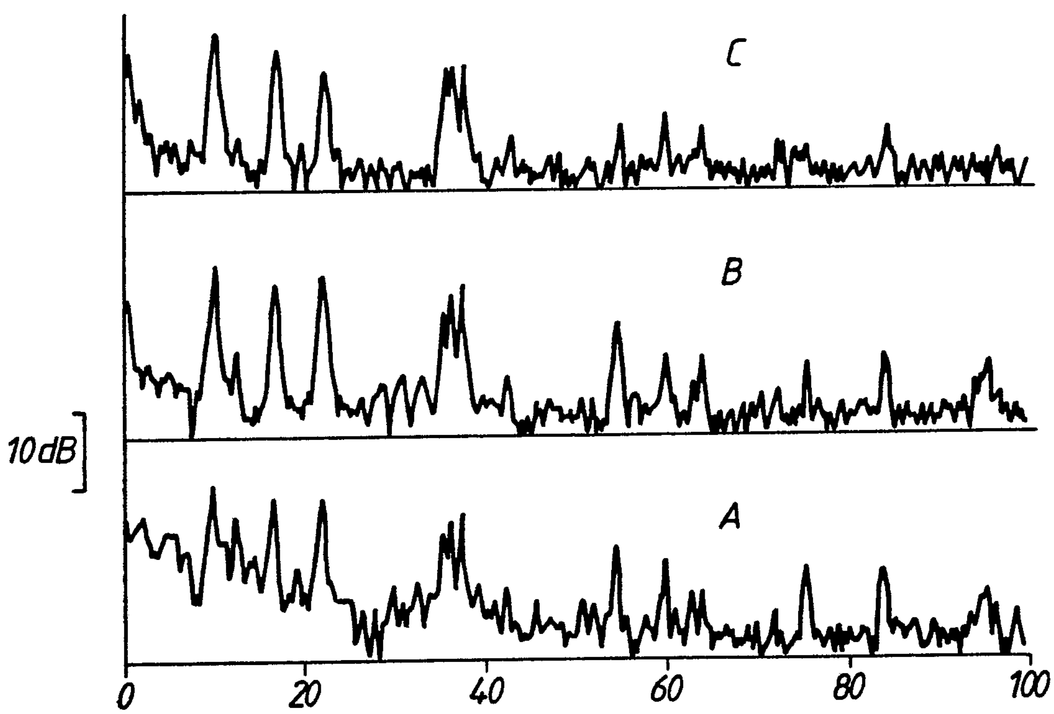


FIG.9.

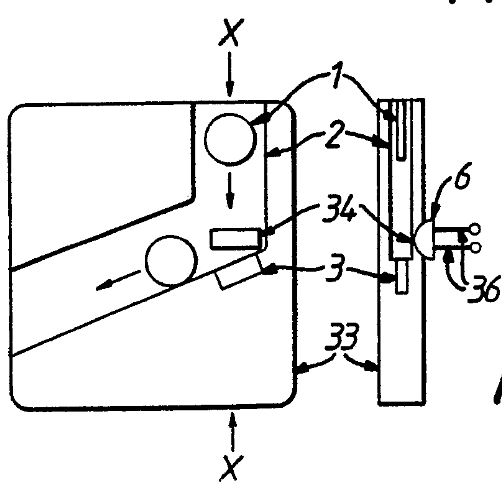
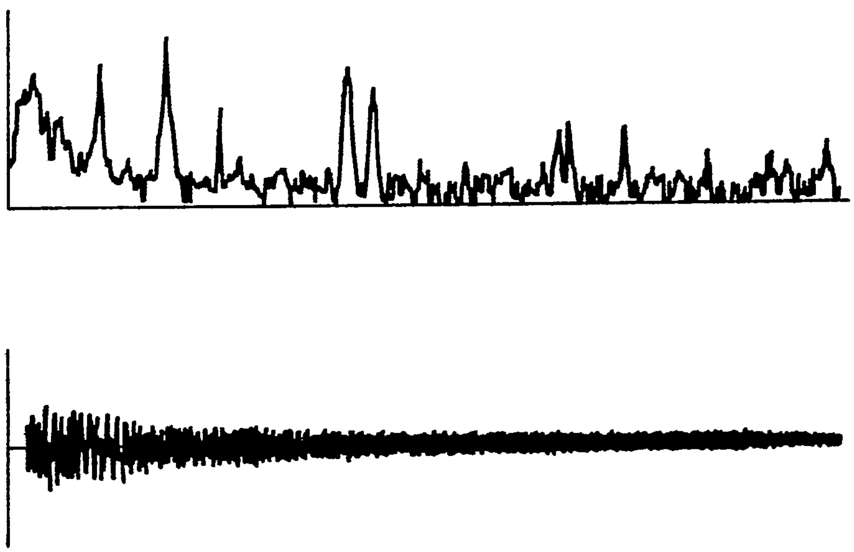
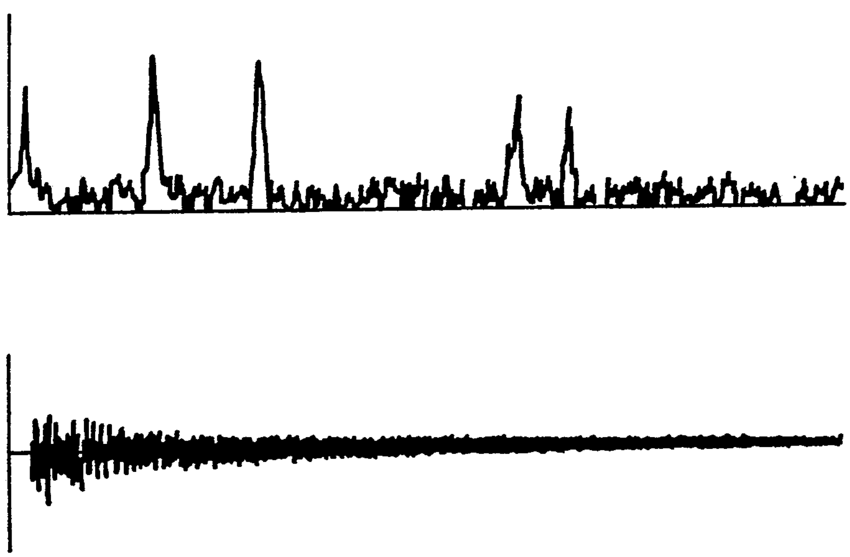


FIG.10.



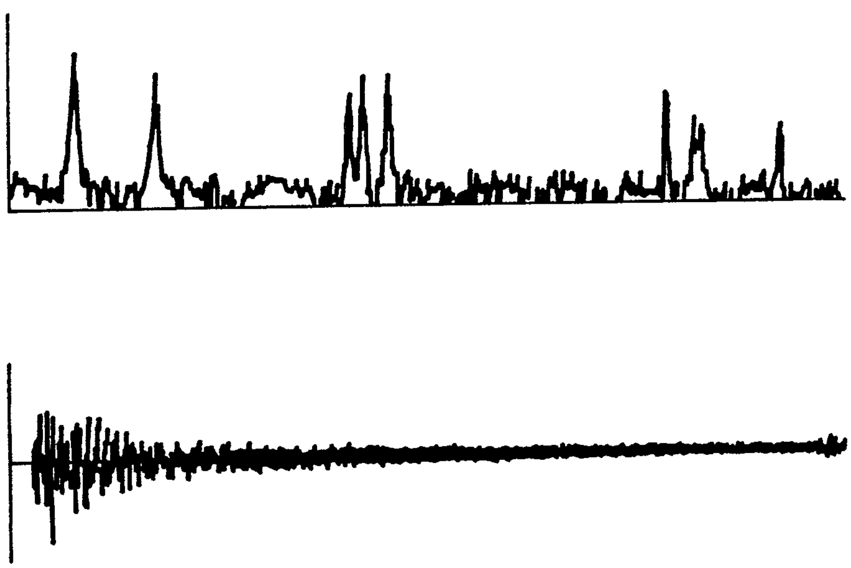
1P - 100kHz SPECTRUM AND TIME RECORD



1P - 10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

FIG. 2.

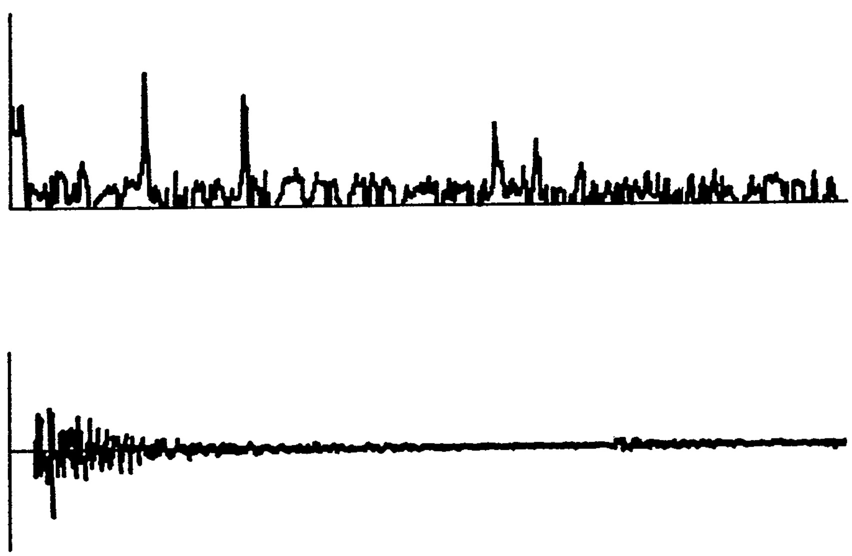
2P - 100kHz SPECTRUM AND TIME RECORD



2P-10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

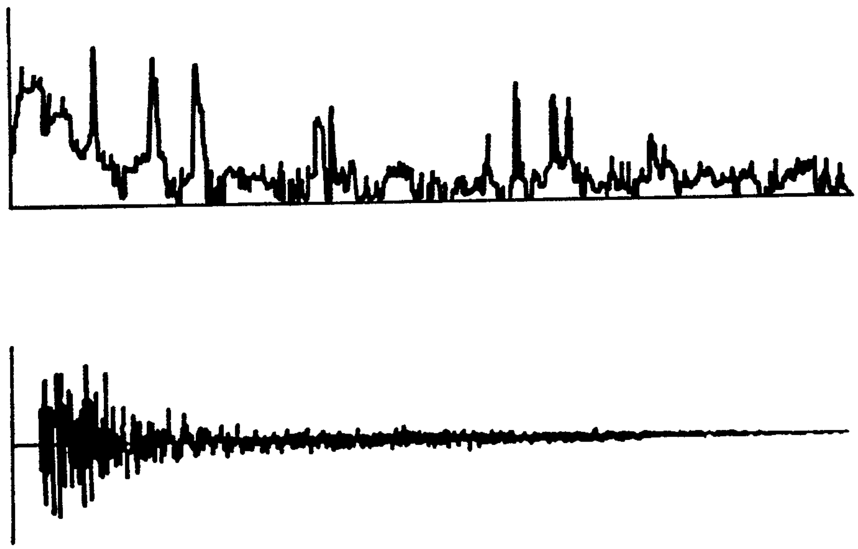
FIG. 3.

5P-100kHz SPECTRUM AND TIME RECORD



5P-10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

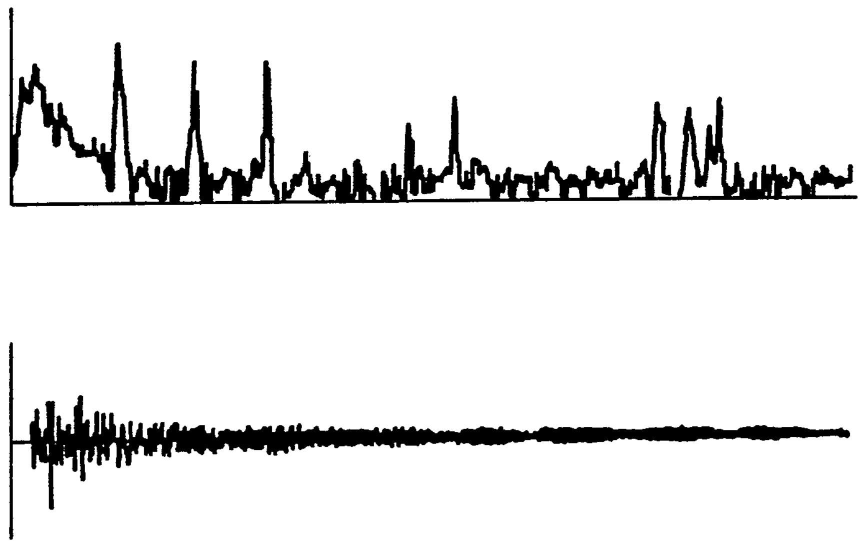
FIG. 4.



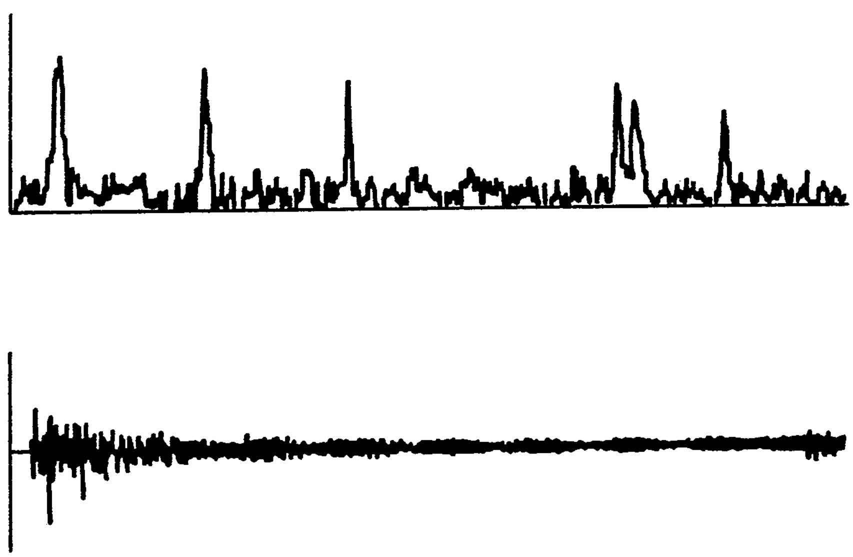
10P-100kHz SPECTRUM AND TIME RECORD

10P-10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

FIG. 5.

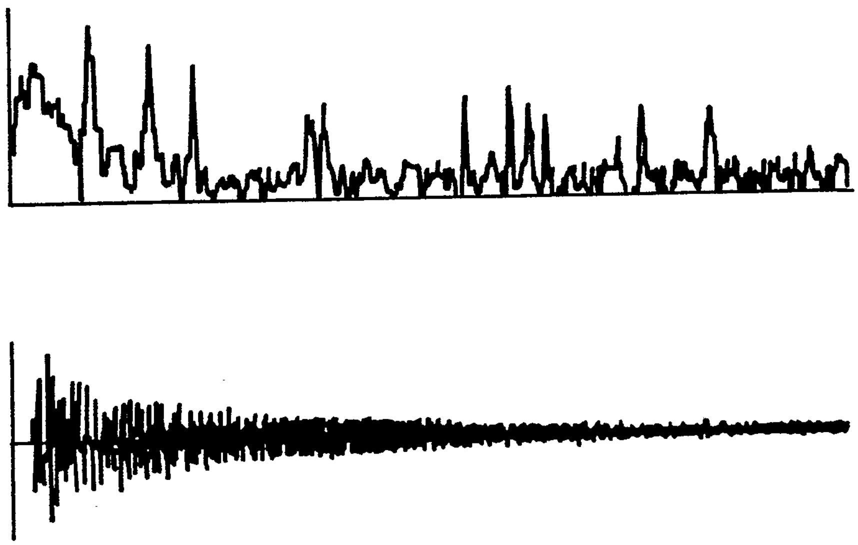


20P-100kHz SPECTRUM AND TIME RECORD

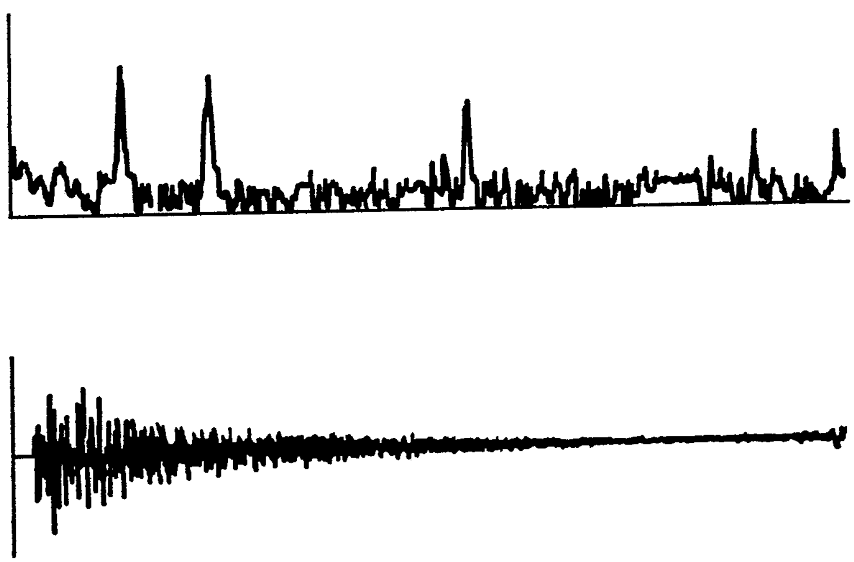


20P-10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

FIG. 6.

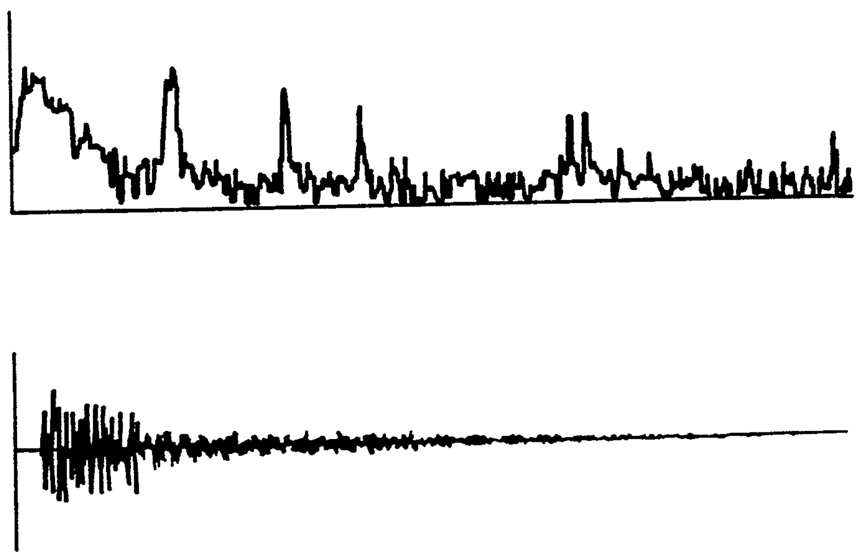


50P-100kHz SPECTRUM AND TIME RECORD

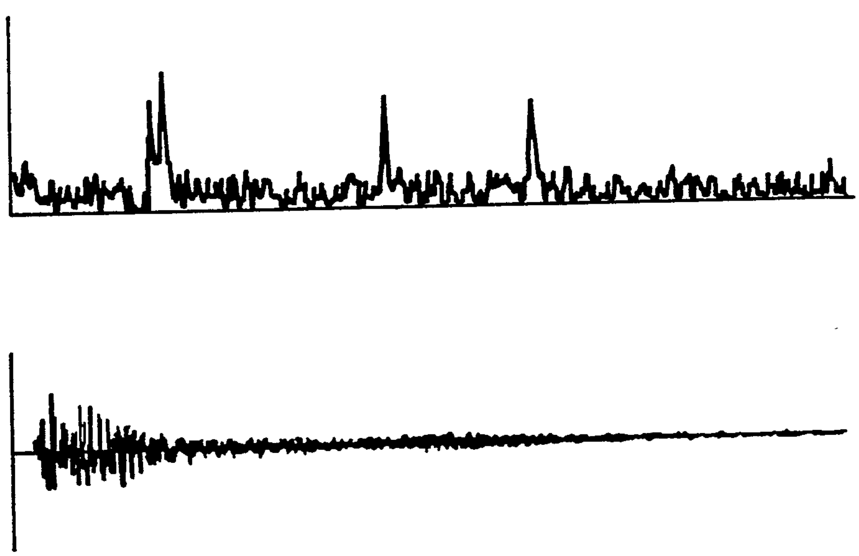


50P-10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

FIG.7.



£1-100kHz SPECTRUM AND TIME RECORD



£1-10kHz-60kHz (EXPANDED) SPECTRUM AND TIME RECORD

FIG.8.

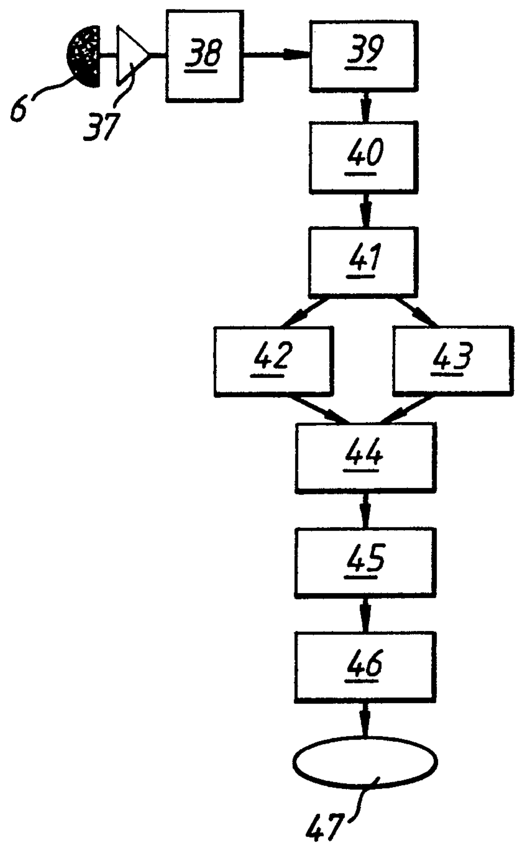


FIG.11.

COIN VALIDATION APPARATUS

This invention relates to coin validation apparatus. It relates particularly to apparatus and a method which is applicable to detecting the values of coins dropped into a slot, and therefore it may be used in a vending machine, a telephone coin box, a coin sorting machine or other suitable device where there is a need to check the values of incoming coins inserted by a potential customer or user.

According to the invention, there is provided a method of validating a coin entering coin validation apparatus, the method comprising the steps of providing a coin chute arranged for directing the entering coin onto a hard striking surface, detecting acoustic vibrations emitted by the said coin upon striking said surface, converting said vibrations to corresponding electric signals, processing said signals to measure the intensity of sound emitted in each one of a series of frequency bands, after a predetermined time interval again detecting acoustic vibrations remaining in the coin and making a further measurement of the sound intensity in said frequency bands, comparing the resulting intensity changes with stored spectra representative of a range of standard coins, and indicating which value of coin corresponds to that having entered said apparatus.

In one embodiment, the said frequency bands are obtained by measuring the frequencies at which the peaks occur in the intensity of the emitted sound. In an alternative embodiment, the said frequency bands have prearranged limits which are determined before the entry of the coin.

The comparison stage may comprise the additional step of measuring the positions of frequency peaks and comparing these with the positions present at the beginning of the said time interval.

The method may also include the step of measuring an extra coin parameter, such as coin diameter, weight or shape, and including the results of said additional measurement in the comparison process.

The invention further includes coin validation apparatus comprising a coin chute including a hard striking surface upon which a coin entering the apparatus is directed, a microphone positioned to detect acoustic vibrations of the coin after striking said surface, an output from said microphone being applied to signal processor means to produce a dynamic signal analysis of the coin vibrations, time delay means arranged to initiate a second signal analysis of the vibrations remaining after said first analysis, comparison means for enabling the two sets of vibration acoustic spectra to be compared with stored spectra representative of a standard set of possible coins, and output means arranged to indicate which coin value of the expected coin set is thereby identified as corresponding to that having entered the apparatus.

The apparatus may include a second time delay means such that the start of the signal analysis operation is delayed by a predetermined time interval after the striking of the said surface.

By way of example, some particular embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows coin validation apparatus for obtaining the acoustic spectrum emitted by a coin,

Figures 2 to 8 are graphs which show the time and frequency structure of the sound emitted by the British coins of denomination 1p, 2p, 5p, 10p, 20p, 50p and £1, respectively,

Figure 9 gives a set of graphs depicting the changes of intensity at different time periods,

Figure 10 shows the mechanical parts of a coin validation apparatus, and,

Figure 11 gives a block diagram of the associated electrical circuit.

When a coin is struck against a hard object, it will vibrate with a characteristic set of modes, determined by the metal from which it is made and the dimensions (thickness, diameter if the coin is circular and any other dimensional features, such as the presence of facets, holes or regions of differing composition). The sound emitted by the coin will contain information about these resonant modes, whose relative amplitudes will change with time after the coin has been struck. Figure 1 shows an apparatus which can be used to obtain the acoustic spectrum emitted by a coin. The coin 1 is allowed to drop down a chute 2 to strike a resilient plate where it emits sound. The sound emitted 4 is detected by a microphone 6, which can be a device such as a Bruel and Kjaer 4135 or any other microphone type which will cover the frequency band containing the modes of interest (the lowest frequency is likely to be around 10KHz, the highest between 40 and 100KHz). The signal from the microphone is amplified, recorded and analysed. One particularly suitable microphone for this is a device using the piezoelectric plastics material PVDF.

Figures 2 to 8 show the time and frequency structure of the sound emitted by the British coins of denomination 1p, 2p, 5p, 10p, 20p, 50p and £1, respectively. These spectra were obtained by analysing the acoustic signals using a Hewlett Packard HP3561A Dynamic Signal Analyser and they are displayed in the figures over the ranges zero to 100KHz and zero to 60KHz. Each spectrum was obtained by carrying out a Fourier transform of the acoustic spectrum collected in a four millisecond interval of time which was arranged to begin approximately eight milliseconds after the coin had struck the inclined plate 3 in Figure 1. It was not found necessary to let the coin travel freely through the air adjacent to the microphone in order to be able to collect the acoustic spectrum sample. Furthermore, it was found that the relative amplitudes of the peaks in the acoustic spectrum from a given coin changed markedly with time as the damping of the different modes of vibration is different.

The peaks in the acoustic spectra are characteristic of the coin denomination and Table 1 lists the frequency bands up to 50KHz in which major and minor resonant peaks of these spectra occur for the coin set members.

TABLE 1

Denomination / Frequency Band	5p	10p	20p	50p	£1
9.4 - 9.8		B		A	
9.9 - 10.5	A	A		A	
12.8 - 13.2			A		
16.8 - 17.2		A		A	
17.9 - 18.8	A				A
18.8 - 19.5					A
21.6 - 21.8			A		
21.9 - 22.0				A	
22.1 - 22.4		A			
23.9 - 24.1	A				
29.9 - 30.3			A		
31.1 - 31.3				B	
31.6 - 33.0					A
35.4 - 35.9				B	
36.0 - 36.5				B	
37.5 - 38.4		B		A	
39.3 - 39.4	A				
40.8 - 42.1	A				A
46.3 - 46.6			B		
47.1 - 47.5			A		
48.9 - 49.0				A	
49.1 - 49.2		A			

"A" indicates a clear resonant peak

"B" indicates a secondary peak, or variation between coins of the same denomination but of different ages.

Close inspection of the spectra reveals that there are very significant differences between most coins, so that it is possible to obtain good discrimination between most of these coin denominations on the basis of the acoustic signature alone. However, certain coin denominations produce similar spectra, the differences between them being quite subtle. For example, the signals obtained from the ten pence and fifty pence coins correspond very closely. This is because the two coins are made from the same metal (a cupro-nickel alloy) and are very similar in linear dimensions, the major difference between the two coins being that the ten pence coin is circular with a diameter of 28.35 millimetres while the fifty pence coin possesses seven rounded facets, with a radius of 29.95 millimetres. The precise frequencies in kilohertz of all the major peaks in the spectra of the fifty pence and ten pence coins are given in Table 2.

TABLE 2

50p	10p
10.08	10.08
12.28	12.28
17.10	17.11
19.39	19.30
22.10	22.37
36.40	37.71 (Broad Peak)
39.04	
55.26*	56.32*
58.07	57.90
61.23	60.53
64.91*	65.70*
	66.75
76.32	75.88
77.19	76.75
85.09*	
96.49	96.49

The preferred peaks which are capable of being used for discrimination have been marked with an asterisk. It can be seen that, in order to discriminate between these two coin types by the acoustic signature alone, it would be necessary to analyse the signature of the coin at frequencies up to 100KHz, with a frequency resolution of better than 0.5KHz. Whilst this is possible, the task of carrying out the signal analysis by, for example, fast Fourier transformation (FFT) becomes increasingly difficult as the upper frequency and the frequency resolution increase. This is because it is necessary to digitally sample the signal at a frequency which is at least twice that of the highest frequency required and for a time which is the inverse of the minimum resolved frequency. Hence, to achieve the above maximum frequency (f_{max}) of 100KHz at 0.5KHz resolution (f_{res}) would require the use of a 200KHz sampling rate for a total sample time of two milliseconds. As the time taken to perform a FFT depends on the number of data points, reducing f_{max} and increasing f_{res} makes the process both faster and cheaper. It can be seen from this that it can be beneficial to incorporate some further characteristic of the coin into the discrimination analysis.

It will readily be appreciated that the different modes of vibration of the coin will be damped differently and will therefore decay at different rates of time. This is shown by the changes in the spectra for a fifty pence coin illustrated in Figure 9. In the Figure, the graphs shown are drawn on a horizontal axis where frequency is measured from zero to one hundred kilohertz. The vertical axis shows amplitude and a scale corresponding to an amplitude change of ten decibels is indicated. The spectra shown were taken over the periods 8 to 12 milliseconds (Curve A), 20 to 24 milliseconds (Curve B) and 36 to 40 milliseconds (Curve C) after the coin's impact on the hard surface. The changes in the intensities of the main peaks over these time periods are given in Table 3.

TABLE 3

Changes in the sound intensity emitted by a fifty pence coin in specified time periods after impact in a validation apparatus.

Frequency KHz	8 to 12 msec dB	20 to 24 msec dB	36 to 40 msec dB
10.08	23.4	22.3	20.8
12.28	19.2	11.4	7.01
17.1	21.8	19.74	18.7
19.39	12.5	3.6	6.2
22.1	21.8	20.7	15.6
35.1	16.6	16.1	16.1
36.17	18.96	18.2	16.6
37.02	19.74	19.74	16.6
39.04	10.13	5.19	4.9
55.26	15.06	14.54	8.8
58.07	13.51	9.9	9.9
61.23	9.09	6.8	5.2
64.91	9.1	9.9	8.31
76.32	12.5	9.35	4.9
85.09	12.0	10.13	8.6
96.49	8.8	8.8	3.6

Those decay rates are characteristic of the particular coin under test and can be used to determine the coin's denomination, in conjunction with the frequencies of the characteristic modes themselves. This can be achieved by allowing the coin to fall upon the hard surface (called a snubber), adjacent to which is a microphone. Some means is provided for detecting the fall of the coin. This can be either the microphone itself, detecting the acoustic signal from the impact of the coin, or a separate sensor attached to or positioned close to the snubber. Such a sensor could take the form of a piezoelectric element attached to the snubber in such a way that the coin's impact flexes the element to provide a piezoelectric output or a photocell and light emitter could be placed close to the snubber in such a place that the coin cuts the light beam immediately prior to the impact of the coin. The signal from the impact detector is used to trigger the acoustic signal collection and processing circuitry. The acoustic signal detected by the microphone is converted into an AC electrical signal, amplified and digitised using an analogue to digital convertor (ADC). At the end of a predetermined period from impact T_1, the digitised signal is sampled and stored for a period T_2 to give a signal function $S_1(T)$. After a further period T_3 the acoustic signal is again sampled for a period T_4 and stored to give a second signal function $S_2(T)$. Further samples $S_n(T)$ of the acoustic signal can be taken and stored if required as extensions to this method.

The signal $S_1(T)$ is processed by taking its Fourier Transform using a Fast Fourier Transform (FFT) signal processor. The peaks in the resulting function $F_1(T)$ are the resonant modes of the coin, which are stored. This peak information can either be stored as the locations (f_i^1) and heights (h_i^1) of the maxima of the function, or by storing the intensities (I_n^1) of the function in predetermined frequency bands, the predetermined frequency bands being selected to cover all the major peaks in the coins of the given coin set. The signal $S_2(T)$ is also processed by FFT and the new heights are recorded of the resonant modes (h_i^2) or of the new intensities stored in the predetermined frequency bands (I_i^2). In one embodiment, the system is arranged so that the FFT on function $S_1(T)$ is carried out during time period T_3, so that the memory capacity required for the storage of $S_1(T)$ can be used again for the storage of $S_2(T)$. The changes in the h_i^n (δh_i^n) or the I_i^n (δI_i^n) are then computed and recorded. The values of f_i, h_i^n and δh_i^n or I_i^n and δI_i^n are used as feature vectors in a statistical classifier such as a Bayes Classifier (a method well known to those skilled in the art of pattern recognition) and compared with the corresponding values for the coin set from which the unknown coin is to be recognised. It will readily be appreciated that subsequent samples of the sound signal $S_n(T)$ can be processed by the FFT to give further values of h_i^n or I_i^n from which additional changes δh_i^n or δI_i^n can be computed and used as extra feature vectors in the classifier.

A complete coin validation apparatus using the acoustic signals will now be described.

The mechanical configuration is shown in Figure 10. The right hand side portion of Figure 10 is a cross-sectional view taken along the line X-X. The body 33 of the validation apparatus is made from a plastics, metal or any other hard material which can be shaped. Machined into the body is a slot or chute 2 which consists of a substantially vertical portion and an inclined portion. Directly beneath the vertical portion is a plate 3 of some hard material such as an alumina ceramic or other oxide ceramic or a metal such as steel. This plate acts as a snubber against which a coin 1 dropped into the vertical portion of the chute 2 will strike. The plate 3 is mounted so that it is substantially flush with the inclined portion of the chute 2. Mounted in the wall of the vertical portion of the chute adjacent to the plate 3 is an aperture or grille 34, behind which is situated a microphone 6 with the appropriate characteristics. Leads 36 connect this microphone with the following electronics. The electrical signals from the microphone 6 are used by the following electronics to validate the coin.

Figure 11 is a block diagram of the associated electrical circuit. In the diagram, the microphone 6 is connected through an amplifier 37 to an analogue to digital convertor 38. A sample of the signal passing through the converter 38 can be fed into a memory block 39. A block 40 of logic circuitry is used to take the data stored in the memory block 39 and produce a fast fourier transform spectrum. The intensities occurring in the preselected frequency bands f_i are selected by a logic block 41 and stored in a memory block 42. While the FFT process is proceeding, a further sample of the acoustic signal is taken and stored in the memory block 39. This signal is fourier transformed and the resulting intensity spectrum stored in a memory block 43. The data in the memory blocks 42 and 43 are acted upon by an arithmetic processor 44 to compute the feature vectors which are stored in a further memory block 45. A statistical classifier 46 then acts upon these feature vectors to give a classification result 47.

The result of the classification operation is used to drive a set of signal lines to predetermined logic levels to pass the information on the classification and enable another electronic or electrical system to operate.

It will be appreciated that alternative circuits could be used for conducting this system function. For example, the acoustic signal can be passed through a filter bank, preset at the frequencies f_i, with the level of signal passing through each filter giving the values of I_i. Alternatively, a single tuneable filter can be used which is tuned through the set of f_i sequentially. As a further alternative, the acoustic signal can be mixed with a local oscillator signal, which can be tuned and subsequently passed through a filter of fixed frequency. Tuning the local oscillator frequency and monitoring the signal passing through the filter permits a measurement of the signal strength in each of the frequencies f_i as a function of time.

The foregoing description of an embodiment of the invention has been given by way of example only and a number of modifications may be made without departing from the scope of the invention as defined in the appended claims. For instance, the coin validation apparatus is not restricted to use with the coins of the United Kingdom coin set and it should be capable of identifying the coins of any other coin set.

The step of triggering the operating electronics so that they will operate only when needed can be useful to exclude unwanted signals and give power economy. Instead of the triggering means specifically described, an alternative means would be to use an electromagnetic sensor consisting of a permanent magnet and concentric coil situated adjacent the chute such that the falling coin in the vertical portion of the chute passes it immediately before striking the snubber. The eddy currents generated in the coin will induce an electric current in the coil which can be used to trigger the following electronics.

As a further refinement of the validation apparatus, the walls of the chute can be lined with an acoustically dead material in order to reduce unwanted sounds due to the coin rubbing or rattling against them. Suitable materials for this purpose include plastics foam sheeting, real or artificial leather, cardboard and paper.

CLAIMS

1. A method of validating a coin entering coin validation apparatus, the method comprising the steps of providing a coin chute arranged for directing the entering coin onto a hard striking surface, detecting acoustic vibrations emitted by the said coin upon striking said surface, converting said vibrations to corresponding electric signals, processing said signals to measure the intensity of sound emitted in each one of a series of frequency bands, after a predetermined time interval again detecting acoustic vibrations remaining in the coin and making a further measurement of the sound intensity in said frequency bands, comparing the resulting intensity changes with stored spectra representative of a range of standard coins, and indicating which value of coin corresponds to that having entered said apparatus.

2. A method as claimed in Claim 1, in which the said frequency bands are obtained by measuring the frequencies at which the peaks occur in the intensity of the emitted sound.

3. A method as claimed in Claim 1, in which the said frequency bands have prearranged limits which are determined before the entry of said coin.

4. A method as claimed in Claim 2, comprising the additional step in the comparison stage of measuring the positions of frequency

peaks and comparing these with the positions present at the beginning of said time interval.

5. A method as claimed in any one of Claims 1 to 4, comprising the further steps of measuring an extra coin parameter, such as coin diameter, weight or shape, and including the results of said additional parameter measurement in the comparison process.

6. A method as claimed in any one of Claims 1 to 5, in which the step of making a further measurement of the sound intensity is repeated two or more times.

7. Coin validation apparatus comprising a coin chute including a hard striking surface upon which a coin entering the apparatus is directed. a microphone positioned to detect acoustic vibrations of the coin after striking said surface, an output from said microphone being applied to signal processor means to produce a dynamic signal analysis of the coin vibrations, time delay means arranged to initiate a second signal analysis of the vibrations remaining after said first analysis, comparison means for enabling the two sets of vibration acoustic spectra to be compared with stored spectra representative of a standard set of possible coins, and output means arranged to indicate which coin value of the expected coin set is thereby identified as corresponding to that having entered the apparatus.

8. Apparatus as claimed in Claim 7, in which a second time delay means is included whereby the start of the signal analysis operation

is delayed by a predetermined time interval after the striking of the said surface.

9. Coin validation apparatus, substantially as hereinbefore described with reference to any one of the accompanying drawings.

10. A method of validating a coin entering coin validation apparatus substantially as hereinbefore described.

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