LASER PUMPING SYSTEMS WITH A DOSAGE CAPACITOR FOR USE IN LIDARS

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In this paper we analyze the operation of an inverter with a consecutive capacitor commutation in application to pumping of lasers of lidar complexes. In doing so we have derived basic relationships to be used for calculations of laser pumping systems aimed at providing broad range of the output parameter change. We also show in this paper that use of coarse and fine regulation of the charging process in the pumping systems of lasers which are based on inverters with a consecutive capacitor commutation could essentially increase the pulse repetition frequency of a lidar transmitter.

Laser pumping systems of lidar transmitters essentially effect the dynamic and accuracy characteristics of lidar systems. Improvements of functional capabilities of such laser pumping systems could seriously improve basic performance parameters of lidars. Thus, for example, a possibility of regulating output voltage of a laser power supply in order to provide the pulse-to-pulse change according to a certain law could expand the dynamic range of a lidar recording system.

For example, in Ref. 1 a possibility is shown to extend the dynamic range by pulse-to-pulse change of optical attenuators at the input to the lidar optical receiving system. In this case use of a software procedure of matching of a series of lidar returns could be helpfull for extending the dynamic range of a lidar recording system. However, performance characteristics of such a mechanically changeable set of optical filters are too poor because of low speed of operation. It is obvious that some electronic systems of such a kind could be much faster.

In this paper we propose to regulate the output power of laser pulses, instead of received power regulation, by a pulse-to-pulse change of the voltage applied to the storage capacitor of an electric pumping system of a laser. Such a change of voltage is possible at a frequency of 100 Hz and higher. In this connection use of charging units based on the use of autonomous inverters with a consecutive commutation could be of a practical interest when designing laser transmitters of lidars.

However, the operation of an inverter with a consecutive capacitor commutation is poorly studied from the stand point of the accuracy and dynamic characteristics of charging units. The lack of such knowledges of these units does not allow the estimation of their applicability to a wide–range lidar and other optical measuring systems to be made. For these reasons it is worth studying the operation of multipulse charging units based on a thyristor key with the consecutive capacitor commutation aimed at looking for versions of such charging units that could suit the requirements imposed on the laser pumping systems of lidars best of all.

Let us now consider how a charging device of such a type is functioning with a resistive-capacitive load. Most common electric circuit for a charging device with a commutative capacitor is shown in Fig. 1. A commutative capacitor is in one arm of a thyristor bridge circuit. Let the capacitor C_k be charged so that its lower plate is at a positive potential. Then unlocking the thyristors *T1* and *T4* we initiate the process of recharging along the path from a power supply E via *T1*, dosage capacitor, C_k, thyristor *T4* current limiting resistor R_{bal}, storage capacitor C_{st}, and back to E. The charge current vanishes as the recharge process stops what immediately locks the thyristors *T1* and *T4*, the polarity of the voltage at C_k becomes reversed. In the next cycle of charging, another one arm of the thyristor bridge will work, i.e., *T3* and *T2* thyristors are open. As a result, at the beginning of each charging cycle we have the polarity of voltage applied to the capacitor that coincides with the polarity of a power supply, so that the voltage stimulating the charge is equal to the sum of the power supply voltage and the voltage at the capacitor.

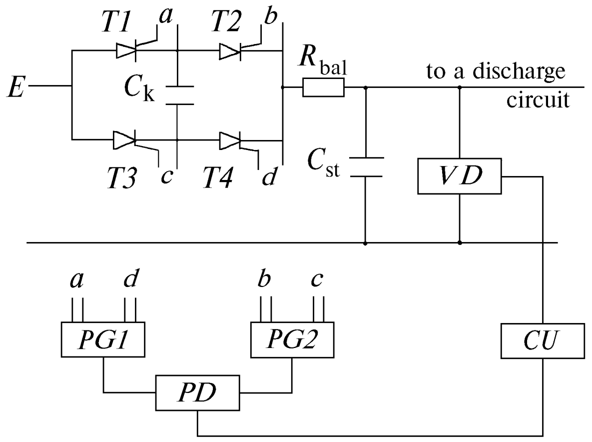

FIG. 1. Block–diagram of a charging device with a dosage capacitor: a voltage divider (VD), control unit (CU), pulse distributer (PD), and pulse generators (PG1 and PG2), which triggers the thyristors T1 and T4 and T2 and T3, respectively

In parallel to the storage capacitor C_{st} there is a voltage divider connected to the circuit to match the high- and low-voltage parts of it. Signal proportional to the voltage at the storage capacitor, C_{st} comes to a control unit (CU). If the voltage at C_{st} is lower than a preset value the control unit produces trigger pulses, and in the case when the voltage at C_{st} reaches a preset value no such pulses produced. The trigger pulses from CU arrive at the pulse distributor (PD), which performes, alternatively, the trigger of generators of trigger pulses, *PG1* and *PG2*. The pulse generator *PG1* triggers the thyristors *T1* and *T4*, while the generator *PG2* makes this to

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thyristors $T2$ and $T3$, thus providing for alternative operation of the two arms of the thyristor bridge.

According to Ref. 2 the voltage at the storage capacitor C_{st} is described as follows

$$U_{C_{st}}(n) = E\,[1 - (N / (N + 1))^n]\,, \qquad (1)$$

where n is the number charging cycles, $N = C_{st}/C_k$.

Let us now consider basic relations of the uncertainty in $U_{C_{st}}$ to the values C_k and C_{st}.

First, let us write Eq. (1) in the form

$$U_{C_{st}} = E\,[1 - 1 / (1 + (1 / N))^n]\,. \qquad (2)$$

Then, using expansion into Taylor series and taking into account that $N > 1$, we obtain

$$U_{C_{st}} = E\,[1 - N / (N + n)]. \qquad (3)$$

If the range of voltage variation at the output of the power supply is U_{min} to E the lower limit of the voltage regulation can be written as

$$\gamma_{low}\, E = E\,[1 - N / (N + n)]\,, \qquad (4)$$

where $\gamma_{low} = U_{min}/E$.

Assuming an increase of voltage at the storage capacitor reached per one cycle of charging to be less than the relative uncertainty in the output parameter α we have

$$\alpha\, \gamma_{low} = N\,(1 / (N + n) - 1 / (N + n + 1))\,. \qquad (5)$$

From expressions (4) and (5) one can obtain that

$$n_{low} = (1 - \alpha\, \gamma_{low} - \gamma_{low}) / \alpha\,; \qquad (6)$$

$$N = (1 - \alpha\, \gamma_{low} - \gamma_{low})\,(1 - \gamma_{low}) / \alpha\, \gamma_{low}\,. \qquad (7)$$

Given the value of relative uncertainty in the output parameter at the lower limit of the voltage regulation one can find from Eqs. (6) and (7) the number of charging cycles and the ratio of a storage and commutative capacities.

The number of cycles sufficient to charge the storage capacity to the voltage U_{tr}, at the power supply voltage E, is

$$n = N\,\gamma / (1 - \gamma)\,, \quad \gamma = U_{tr} / E\,. \qquad (8)$$

As follows from Eq. (7) the proportion between the commutative and storage capacities depends on both the uncertainty α in the output parameter and the range of its change. The function $N = f(\gamma)$ is plotted in Fig. 2 for different relative uncertainty, α, of the output parameter. As is seen from the curves in this figure, the coefficient N increases with increasing width of the output parameter regulation range. Much stronger is the dependence of N on the relative uncertainty in the output parameter.

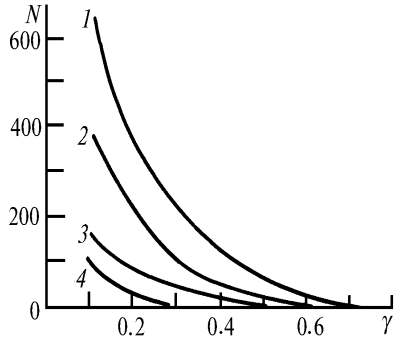

FIG. 2. The function $N = f(\gamma)$ for different relative uncertainties in output parameter: $\alpha = 0.01$ *(1),* 0.02 *(2),* 0.05 *(3), and* 0.1 *(4)*

The higher is the upper limit of the voltage regulation the lower is the charging rate, because the number of charging cycles increases. If the voltage to be applied to the storage capacitor equals the output voltage of a power supply then the number of charging cycles tends to infinity. However, in fact we normally have some uncertainty in the charging voltage and hence we can take that $\gamma = 1 - \alpha$. Taking into account this circumstance we can estimate the number of cycles necessary to charge the capacitor to the power supply voltage E accurate to α

$$n_{max} = N\,(1 - \alpha) / \alpha\,. \qquad (9)$$

Figure 3 shows the dependence of the number of charging cycles on the value of the upper limit of voltage regulation at different lower limits of regulation and $\alpha = 0.1$.

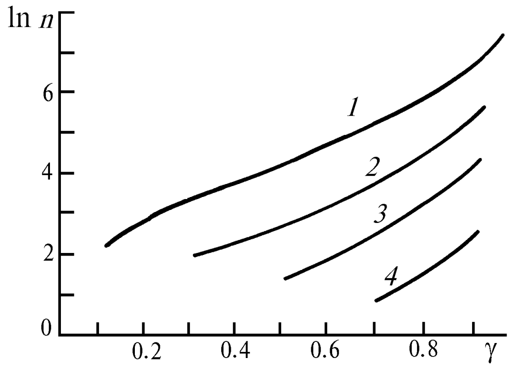

FIG. 3. The function $n = f(\gamma)$ for relative uncertainty in output parameter $\alpha = 0.1$ at various values of lower limit of regulation: $\gamma_{low} = 0.1$ *(1),* 0.3 *(2),* 0.5 *(3), and* 0.7 *(4)*

With the increase of the upper limit of voltage regulation from 0.1 to 0.95 E the number of charging cycles rapidly increases to 1480. As can be obtained based on these considerations, at a 10 kHz frequency of charging pulses the maximum pulse repetition frequency of a lidar transmitter doesn't exceed 7 Hz.

As a result, we can state that the main disadvantage of this pumping system with a dosage capacitor is low pulse repetition frequency if a lidar system requires wide range of regulation of its output power.

An essential increase of the repetition frequency can be achieved if a multistage charging system is used to charge the storage capacitor or if the charging of the capacitor is made using a combination of coarse and fine charging cycles. We shall consider the latter approach in more detail.

In this case the storage capacitor is first charged with large portions of energy what provides rapid, albeit coarse, charge of the capacitor. Then the capacitor is slowly charged to a preset voltage with small portions of energy providing the desired accuracy of the output parameter setting.

Block-diagram of the charging device with the coarse and fine charging cycles differs from that depicted in Fig. 1 only by an additional dosage capacitor which provides fast though coarse charging of the storage capacitor. This additional capacitor is connected to the main circuit via an additional switch.

Let us now consider some basic properties of such a charging unit. In order to provide fast operation of the charging circuit at a preset relative uncertainty in the output parameter and a wide range of its regulation one should determine proper proportion between the primary and additional dosage capacities.

The required accuracy of charging the storage capacity has to be provided in the whole range of the output parameter regulation. Therefore the capacity of the primary dosage capacitor may be determined from Eq. (7). As a result, N_f is written as follows

$$N_f = (1 - \alpha\, \gamma_{low} - \gamma_{low})\,(1 - \gamma_{low}) \,/\, \alpha\, \gamma_{low} \,. \tag{10}$$

Let us now find the number of fine charging cycles per one coarse charging cycle

$$n_f = N_f \,/\, N_c = N_f\,(\gamma_1 \,/\, (1 - \gamma_1) - \gamma_0 \,/\, (1 - \gamma_0))\,, \tag{11}$$

here $\gamma_1 = (n + 1)/(N_c + n + 1)$ and $\gamma_0 = n/(N_c + n)$.

As follows from Eq. (11), n doesn't depend on the initial charge, $\gamma_0 E$.

The total number of cycles of coarse and fine charging can be written as follows

$$n_{tot} = N_c\, \gamma \,/\, (1 - \gamma) + n_1\,, \tag{12}$$

where n_1 is the number of fine charging cycles.

Assuming the voltage at the storage capacitor to be determined by the maximum number of fine charging cycles (i.e. when $n_1 = n_f$) we obtain

$$n_{tot} = N_c\, \gamma \,/\, (1 - \gamma) + N_c \,/\, N_f \,. \tag{13}$$

Let us now determine the value N_c at which the number n_{tot} takes its minimum. To do this, we shall take the derivative dn_{tot}/dN_c and from the condition that this derivative is equal to zero we obtain

$$\gamma \,/\, (1 - \gamma) - N_f \,/\, N_c^2 = 0 \tag{14}$$

or

$$N_c^2 = N_f\,(1 - \gamma) \,/\, \gamma \,. \tag{15}$$

Maximum value of N_c^2 corresponds to $\gamma = \gamma_m$, therefore Eq. (15) can be written in the form

$$N_c = \sqrt{N_f\,(1 - \gamma_m) \,/\, \gamma_m}\,. \tag{16}$$

The maximum number of charging cycles that provides reaching the voltage U_m can be presented as follows

$$n_{tot} = \gamma_m \,/\, (1 - \gamma_m)\sqrt{N_f\,(1 - \gamma_m) \,/\, \gamma_m} + \sqrt{(1 - \gamma_m) \,/\, \gamma\, N_f}\,. \tag{17}$$

The number of cycles sufficient to provide the voltage $U_{C_{st}} = \gamma \cdot E$ at the storage capacitor is determined by the following formula

$$n_{tot} = n_c + n_f\,, \tag{18}$$

where $n_c = N_c(\gamma/(1 - \gamma))$ (only integer part of n_c is taken here because the charging of the storage capacitor is done by portions).

The number of fine charging cycles can be found from the following expression

$$n_f = \{n_c\}\, N_f \,/\, N_c\,, \tag{19}$$

where $\{n_c\}$ is the fractional part of n_c value.

Taking into account Eqs. (18) and (19) the number of charging cycles necessary to achieve the voltage γE can be written as follows

$$n_{tot} = \mathrm{int}\,(\gamma\, N_c/\, (1 - \gamma)) + \{n_c\}\, N_f \,/\, N_c\,. \tag{20}$$

Let us now estimate the advantage of using a circuit with two dosage capacitor compared to the single–capacitor circuit. To do this, we calculate the ratio of the numbers of charging cycles under the conditions of one and the same relative uncertainty in an output parameter

$$K_a = n_1 \,/\, n_f = (\gamma\, N_f\, N_c) \,/\, (\gamma\, N_c + (1 - \gamma)\, N_f\,)\,. \tag{21}$$

The dependence of K_a on γ is shown in Fig. 4 for different values of the relative incertainty in the output voltage. As is seen from this figure, the value K_a reaches its maximum at $\gamma = \gamma_m$. It is characteristic that the higher are the accuracy requirements to the charging device the more advantageous is the use of circuitry with two dosage capacitors.

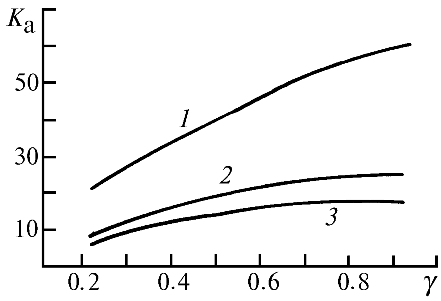

FIG. 4. The dependence $K_a = f(\gamma)$ for a single additional dosage capacitor: α = 0.01 *(1),* 0.05 *(2), and* 0.1 *(3)*

Thus, it can be stated in conclusion that use of coarse charging allows the operation rate of a system of pumping solid state lasers to be essentially increased at a high accuracy of the output parameter setting.

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