Currentology for the Constructal Theory

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Abstract

Presented an attempt to describe flows of mass, impulse, electrical charge,energy , entropy, exergy and information in the standard divergence form of differential equations for the vectors of their currents, entitled as Currentology. The easiest access of a selected current by possible variation of boundary conditions according to Constructal Theory would determine the shape of the system.

Nomenclature

A = magnetic potential, **B** = magnetic induction, **D** = electrical induction, **E** = electrical field, e = specific energy, F = cross-section, I = information (amount), I* = flow of information, i = information in unit of volume, **J** = current density vector, G = chemical potential, **H** = magnetic field, h = specific enthalpy, k =Boltzmann constant, L = length, **M** = magnetization, **P** = polarization, p = pressure, P_{ik} = mechanical stress tensor, q = specific electrical charge, S = entropy (amount), S* = entropy flow, s =specific entropy, T = temperature, U = internal energy per unit of mass,**V** = velocity,
v = 1/ρ = specific volume, W = work, **e** =specific exergy.
α = thermoelectric coefficient, γ = electrical conductivity, **δ** = energy current vector, δ_{ik} = tensor unity, ε=electrical permeability, μ = magnetic permeability, ρ = mass density, σ = entropy gain intensity, τ_{ik} =tangential stress tensor, φ = electrical potential, ω = rotational frequency.
Subscripts : i = information, q = electrical charge, s = entropy, ik = tensor components, o = vacuum or reference.
Vectors printed in bold, vector product is with ×, scalar product of vectors is with •,
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Introduction

The main principle of Constructal Theory is expressed by A.Bejan as "easiest access".
His full formulation:
" *For a finit –size system to persist in time (to live), it must evolve in such a way that it provides easiest access to the imposed **currents that flow** through it*". Just currents are subjects of Constructal Theory. For that matter the calculations of currents plays an important role.
Here is presented the unified description of currents of mass, impulse, charge , energy and exergy in the form of divergency equation of their currents, forming conservation or nonconservation Law.
Equations are based on the Landau-Lifshits textbooks on Hydrodynamics and Electrodynamics (in SI unit system) and book of Gyarmati. The wording "easiest access" means the least resistance, least entropy gain or minimal generalized friction by variation of boundary conditions, which determines the shape of a considered system. Sometimes the easiest access means the minimum of exergy losses or maximum of exergy efficiency. In engineering systems exists the essencial question, should the invested exergy be included in exergy losses ? The answer depends on a case conditions. If there are many criterions to optimize the Pareto optimization might be used (Yantovski and Zack, 2000)

Let us consider a conservation Law in the divergence form of differential equation for a quantity Q:

$$\partial Q/\partial t + \mathrm{div}\mathbf{J} = g \qquad (1)$$

Here **J** = vector of the current of Q, g = gain or sink (negative gain) of the Q. If g = 0 equation (1) means a conservation law.
It is well known the Gauss theoreme for steady-state flow: the total quantity of Q, born in the given volume V equals the flow of vector **J** through the surface F, surrounded V. Here **n** is a vector unit, normal to F. It means

$$\iiint_V g\,dV = \iint (\mathbf{J.n})\,dF \qquad (2)$$

Now to select a particular case the particulate vector **J** and the specific gain g should be found. The Q might be mass, impulse, electrical charge, energy, entropy and exergy.
Eq.(1) and (2) describe processes in hydrodynamics, thermodynamics and electrodynamics.
As it goes on flows or currents, no assumption of equilibrium in ordinary thermodynamic sense is valid. These topics are described by Non-equilibrium Thermodynamics (NeT) when the local equilibrium takes place and even in a gas flow is possible to identify the definite pressure and temperature in a point of a flow.
. Present writer last decades tried to find useful equations for thermal and electrical engineering (Yantovski, 1989, 1997a, 1997b, the book of 1994). In the paper a further development of the same line is presented .Along with entropy and exergy currents it is useful to include the information flow as a current of a negative thermal charge which is treated on the base of concept of thermal charge of both signs.
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Information As Negative Entropy

Leo Szilard(1929, in Leff and Rex) stated, that the creation of one bit of information always is accompanied by k ln2 of entropy. It was the starting point of thermodynamics of information similar to origination of classical Thermodinamics by Sadi Carnot. Last decades many authors developed further this discovery.

Modern Wikipedia cites the statement of G.N.Lewis about chemical entropy in 1930:"Gain in entropy always means loss of information and nothing more". And then in Wikipedia:"…posession of a single bit of Shannon information (a single bit of negentropy in Brillouin's term) really does correspond to a reduction of physical entropy, which theoretically can indeed be converted into useful physical work".

Brillouin (1956, in Leff and Rex) „ Every physical measurement requires a corresponding entropy increase, and there is a lower limit, below which measurement becomes impossible. This limit corresponds to change in entropy of...k ln2 or approximately 0.7 k for one bit of information obtained."

Zemansky (1968) „A convenient measure of information, conveyed when the number of choices is reduced from Wo to W1 is given by I = k ln(Wo/W1). The bigger the reduction, the bigger information. Since k lnW is the entropy S, then S1 = So - I, which can be interpreted to mean that the entropy of a system is reduced by the amount of information about the state of the system...The increase of information as a result of compression is seen to be identical with the corresponding entropy reduction".

Weinberg (1982, in Leff and Rex): „We can quantify the information per measurement or per bit, it is I = -k ln2,the negative sign meaning that for each increase in information there is a decrease in actual physical entropy".

Machta (1999):" Students are now comfortable with the notion that information is physical and quantitatively measurable... definite amount of information may be stored in digital form on hard drives and other storage media and in dynamic memory... the information content of a record is the number of bits (ones or zeros) needed to encode the record in the most efficient possible way. This definition is formalized by algorithmic information theory... Suppose that the hard drive is initially filled with a record which is the result of 8 billion coin tosses. The entropy, associated with information-bearing degrees of freedom will be k (8.10^9)bits. Suppose that disc is erased... To satisfy the Second Law an equal or greater increase of entropy must have occured... a tiny amount of heat k (8.10^9)(300 K) = $2.3.10^{-11}$ J must be released". According to known Landauer principle „there is a minimum dissipation of kT whenever a bit of information is erased in an environment at temperature T".

Schlögl(1989): „... the development of the microstate in time is not exactly known. The description is restricted to probabilities over microstates. The information associated with their distribution cannot increase after the last observation. In thermal states this information is a function I(M) of the state variables. Consequently there exists function which has the mentioned features of entropy:

S(M) = - k I(M)

This identification of macroscopic entropy with the lack of information about the microstate is the basic link between statistics and phenomenological Thermodynamics".

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Frankly speaking we should look at the works of rare authors rejecting any link of information and thermodynamic entropy, but vast majority admit that the relation between information entropy and thermodynamic entropy has become the common currency in Physics.

Thermal Charges

All the students easily accept the electrical energy transfer by conduction of electrical charges through a metallic conductor. Here electrical charge is an energy carrier. The conductive transfer of thermal energy we call heat has an another carrier, the entropy. We define this process as conduction, because the substance, in which entropy flows might be at rest. Similar to electrical current, the entropy current takes place relative to a substance. Regardless to possible statistical interpretation of entropy it plays in a conduction process a role of a charge flow.

When electrical space charge is transferred by moving insulator it is a convective electrical current, similar process is the convective transfer of thermal energy by flow of hot water. More comments on the conduction and convection division will follow in a separate section.

As we have seen, entropy and information have the same units and differ by sign only, we may treat them as the thermal charge of different signs. They are additive, extensive quantities, their potential (intensive quantity)is temperature. Along with the elemental electrical charge $1.6.10^{-19}$ Coulomb there exists the elemental thermal charge 1 bit = k ln2 (about $1 .10^{-23}$ J/K). Every bit of information by measurement needs not less, than k ln2 entropy production. A measurement might be treated as a kind of splitting of a neutral particle, forming a pair of charges but the thermal instead of electrical ones. When meeting the thermal as well as electrical charges annihilate, if they are of opposite signs.

The sharp contrast between mentioned charges : between electrical ones exist a strong force, creating the field (Coulomb force and Lorentz force when it moves in magnetic field), whereas between thermal charges there are no repulsive or attractive forces and no field.

The most important difference is the strict conservation law for electrical charge (when by splitting of a neutral particle the positive charge is exactly equal to negative one) and the lack of this analogy for thermal charges. Due to Second Law in every real process the positive charge is to be in excess. Only in ideal (reversible) processes thermal charges of both signs are equal, which means a thermal charge conservation for ideal processes.

Generalized Friction

The first observation of electrical charges in ancient times was due to mechanical friction of some pieces of different materials (amber = electron in Greece). Here the splitting of neutral surface molecules takes place by a kind of rubbing. The positive thermal charge always is creating by friction, not only mechanical. There was proposed (Yantovski,1994) the concept of generalized friction, including mechanical, electrical and thermal friction. Mechanical friction does not need any explanation, electrical one is the result of scattering and collisions of electrons in a conductor (electrical resistance and Joule heating) and most important thermal friction is the heat flow over the significant temperature drop. Mixture of different gases or liquids might be associated with chemical friction. To reverse the mixing (to set apart) a significant work is needed. Generalized friction produces positive thermal charge. There exists, however, a possibility to observe some intensive positive thermal charge flow with creating negative ones (producing order from a chaos as in Prigogine's dissipative structures).

In general, friction creates only positive thermal charge, whereas to produce negative ones the work is needed for a separation process. Generalized friction is the cause of irreversibility. The appeal of F.Boshniacovich „ Fight irreversibilities" in our language translates in „Fight friction".

The notorious negentropy of Schrödinger and Brillouin, which is needed to feed living creatures, is just the negative thermal charge, which is neutralized much in excess by metabolic processes. Here, like in every combustion reaction the chemical part of generalized friction takes place.

Equations of Currentology

Most problems in Energy Engineering are described by equations, valid for continua, neglecting relativistic and quantum effects, and assuming local thermodynamic equilibrium. The last means the equilibrium in a volume large enough with respect to mean free path of a gas particle and small enough in comparison with a channel size. It is just our assumptions for currentology, as in ordinary gasdynamics with definite T and P.

The mass conservation equation is:

$$\partial\rho/\partial t + \mathrm{div}\,(\rho\mathbf{V}) = 0 \qquad (3)$$

Electrical charge conservation has a similar form

$$\partial q/\partial t + \mathrm{div}\,\mathbf{J}_q = 0 \qquad (4)$$

The nonconservation of the thermal charges of both signs is described by the two equations

$$\partial s/\partial t + \text{div}\, \mathbf{J}_s = \sigma_s \qquad (5)$$

$$\partial i/\partial t + \text{div}\, \mathbf{J}_i = \sigma_i \qquad (6)$$

with the short formulation of Second Law $\sigma_s \geq \sigma_i$

The sum of (5) and (6), when the latter is multiplied by k gives

$$\partial(s - ki)/\partial t + \text{div}(\mathbf{J_s} - k\mathbf{J}_i) = \sigma_s - k\,\sigma_i \qquad (7)$$

The energy conservation law in the standard divergence form is as follows:

$$\partial e/\partial t + \text{div}\, \boldsymbol{\delta} = 0 \qquad (8)$$

The components of energy **in a substance** are described in an extended Gibbs identity:

$$de = dU + T\, d(s - ki) - p\, dv + \varphi dq + \mathbf{H \bullet dM + E \bullet dP} \qquad (9)$$

Here the shear part of mechanical work is omitted, compression work increases when volume decreases and i itself is considered as positive.

A substance, where all the terms (9) are of comparable magnitude is unknown. If a compressible gas is under consideration, there are no polarization, magnetization and information flow. A solid body, however, might be magnetized or polarized and carry a large amount of information (CD, DVD, sticks and their forthcoming heirs). Here some processes of energy conversion might be depicted on a T-I diagrams, similar to ordinary T-S diagrams (in which S > 0). Instead of isobar or isochor on T-I diagrams the isofield or isopolarization lines are to be used with the possibility of thermodynamic cycles drawing.

Impulse Conservation

As a quantity which obeys the strict conservation law (Newton's law) impulse is much more complicated than mass or electrical charge. We distinguish the mechanical impulse (per unit of volume) $\rho\mathbf{V}$, which coincides to the mass current vector and electromagnetic impulse $\mathbf{D\times B}$, where $\mathbf{B} = \mu_o \mathbf{H} + \mathbf{M}$, $\mathbf{D} = \boldsymbol{\varepsilon}_o \mathbf{E} + \mathbf{P}$.
A complicated case is the interaction of substance and field, when a body has an impulse, being at rest ($\mathbf{V}$=0), when it is polarized and magnetized. It might be true for some new materials as magnetodielectrics or magnetic liquids (colloids of a magnetic in a dielectric liquid).
The two parts of the impulse current are mechanical P_{ik} and electromagnetic M_{ik} currents of impulse, the both are tensors of second rank:

$$P_{ik} = -p\delta_{ik} + \tau_{ik} + \rho V_i\, V_k \qquad (10)$$

$$M_{ik} = - E_i D_k + H_i B_k - \delta_{ik}\, \mathbf{(D\bullet E + B\bullet H)} \qquad (11)$$

For each part of impulse the standard divergency form equations of currentology are as follows:

$$\partial(\rho\mathbf{V})/\partial t + \text{div}\, P_{ik} = q\mathbf{E} + \mathbf{J}_q\times\mathbf{B} \qquad (12)$$

$$\partial(\mathbf{D\times B})/\partial t + \text{div}\, M_{ik} = -(q\mathbf{E} + \mathbf{J}_q\times\mathbf{B}) \qquad (13)$$

The rhs of these equations is the intensity of impulse creation or destroying, which is just the force density (force in unit of volume). The force is the link between the mechanical and electromagnetic parts of impulse. For the total impulse the conservation law is as follows:

$$\partial(\rho\mathbf{V} + \mathbf{D\times B})/\partial t + \text{div}(P_{ik} + M_{ik}) = 0. \qquad (14)$$

Well known effects of mechanical impulse conservation as rocket flight, aircraft, marine propulsion are familiar from the school days. Less known are the effects of the total impulse conservation like a solar light pressure (first measured by P.Lebedev) giving some hopes for space navigation by solar sails. Much higher pressure creates the beam of powerful laser. The forging of plastic metals by a high current discharge or an induction electric motor torque are the other examples.

Energy Conservation

N.A.Oumov in 1874 was the first, presented energy conservation equation as the divergence one:

$$\partial e/\partial t + (\partial eV_x/\partial x + \partial eV_y/\partial y + \partial eV_z/\partial z) = 0. \quad (15)$$

That time there were no symbol div, nevertheless it is evident, that (15) is just divergence-form equation of currentology. In 1884 J.Pointing, using Maxwell's field equations, gave the energy equation for electromagnetic field:

$$\partial(\varepsilon_o E^2 + \mu_o H^2)/2\partial t + \mathrm{div}\,(\mathbf{E}\times\mathbf{H}) = -\,\mathbf{E}\bullet\mathbf{J}_q \quad (16)$$

As usual in a substance the Ohm's law is valid : $\mathbf{J}_q = \gamma\,\mathbf{E}$ and the rhs takes the form $-J^2/\gamma$. This case the field energy in a closed system should always decrease. The sign of rhs might be reversed if there exists an electromotive force, greater than the field **E,** when the Ohm's law is

$$\mathbf{J}_q = \gamma\,(\mathbf{E} - \mathbf{E}_{emf}) \quad (17)$$

Mechanical energy conservation for a compressible, viscous, thermally and electrically conducting substance is as follows:

$$\partial(U + p/\rho + G + V^2/2)\rho/\partial t + \mathrm{div}[(U + p/\rho + G + V^2/2)\,\rho\mathbf{V} + \mathbf{V}\bullet P_{ik} - \lambda\,\mathrm{grad}T] = \mathbf{E}\bullet\mathbf{J}_q \quad (18)$$

The sum of (16) and (18) gives the total energy conservation equation , where rhs is zero:

$$\partial(U + p/\rho + G + V^2/2)\rho + \varepsilon_o E^2/2 + \mu_o H^2/2/\partial t + \mathrm{div}[(U + p/\rho + G + V^2/2)\,\rho\mathbf{V} + \mathbf{V}\bullet P_{ik} - \lambda\,\mathrm{grad}T + \mathbf{E}\times\mathbf{H}] = 0. \quad (19)$$

Here the substance is assumed as nonmagnetized and nonpolarized. In the square brackets is the Oumov-Pointing vector, describing the energy current. From eq.(16) and (19) we learn that it is defined by its divergence only. It means that the addition to it of any solenoidal vector **a** (div**a** = 0) does not affect the equations. Such a vector after Slepian (1942) has been rot(φ**H**) and the Pointing vector **E×H** was transformed into more convenient form

$$\boldsymbol{\delta} = \mathbf{E}\times\mathbf{H} + \mathrm{rot}(\varphi\mathbf{H}) = \varphi(\mathbf{J}_q + \partial\mathbf{D}/\partial t) - \partial\mathbf{A}/\partial t\times\mathbf{H} \quad (20)$$

By definition rot $\mathbf{A} = \mathbf{B}$, $\mathbf{E} = -\mathrm{grad}\varphi - \partial\mathbf{A}/\partial t$.

For a steady-state case, when $\partial(\ )/\partial t = 0$, the modified Pointing vector is

$$\boldsymbol{\delta} = \varphi\mathbf{J}_q \quad (21)$$

and we see that electrical current vector lines coincide with energy vector ones. For a gas flow, which often is a carrier of energy, introducing the entropy current vector

$$T\mathbf{J}_s = \rho\mathbf{V}(U + p/\rho) - \lambda\,\mathrm{grad}T \quad (22)$$

we have the steady-state case of energy current in a substance

$$\boldsymbol{\delta} = (G + V^2/2)\rho\mathbf{V} + \mathbf{V}\bullet\mathbf{P}_{ik} + \varphi\mathbf{J}_q + T\mathbf{J}_s \quad (23)$$

In vacuum the only energy carriers are electromagnetic waves. There no one term of (23) is acting.

EXERGY CURRENT VECTOR

Exergy, the ability to do work in the given reference state is the main concept of modern Energy Engineering. There exists large amount of textbooks on the matter.
Specific exergy is

$\mathbf{e} = G_\in + V^2/2 + U + p/\rho + \mathbf{H}\bullet\mathbf{B}/\rho + \mathbf{E}\bullet\mathbf{D}/\rho - T_o(S - kI)$ (24)

G.Wall(1977) cited the pioneering works by M. Tribus, C.Bennett, R.Landauer and stated after M.Tribus : „...relation between exergy $\in$ in Joule and information I in binary units (bits) is $\mathbf{e} = k' T_o I$, where $k' = k\ln 2 \approx 1.10^{-23}$ J/K“.This early statement is valid if exergy is totally associated with negentropy (the term $-T_oS$). As is evident from (24) there exist many other important terms. .
In (24) as before we count S >0 and I >0. The sum of positive and negative thermal charge times reference temperature T_o represent the lost or gained (Iantovski, 1997a) works. Instead of chemical potential the chemical exergy $G_\in$ should be used. The divergence form of exergy equation in currentology is

$$\partial\mathbf{e}/\partial t + \mathrm{div}\,\mathbf{J}_\in = -T_o(\sigma_s - k\sigma_i) \qquad (25)$$

in agreement with (7). Introducing entropy current (22) in the corresponding exergy current vector we have

$$\mathbf{J}_\in = \rho\mathbf{V}(G_\in + V^2/2 + \mathbf{H}\bullet\mathbf{M} + \mathbf{E}\bullet\mathbf{P}) + \varphi(\mathbf{J}_q + \partial\mathbf{D}/\partial t) - \partial\mathbf{A}/\partial t\times\mathbf{H} + \mathbf{V}\bullet\mathbf{P}_{ik} + (T - T_o)(\mathbf{J}_s - k\mathbf{J}_i) \qquad (26)$$

The simplified steady-state version for a gas flow is (Iantovski, 1997b):

$$\mathbf{J}_\in = \rho\mathbf{V}(G_\in + V^2/2) + \varphi\mathbf{J}_q + \mathbf{V}\bullet\mathbf{P}_{ik} + (T - T_o)\mathbf{J}_s \qquad (27)$$

The last term in case of thermal conduction or convection translates into $(\lambda \mathrm{grad}T)(1-T_o/T)$ or $\rho VU(1-T_o/T)$, not only in a gas, but in liquids and solid bodies.

CONDUCTIVE, CONVECTIVE AND WAVE TRANSFER

In every textbook on heat transfer one may find above mentioned division for thermal energy transfer. Kreuzer (1984) offered to use conduction and convection division for an impulse flow. Looking at (26) and (27) we see the transfer by moving substance $\rho\mathbf{V}$ (convection) and flows through a steady-state substance (conduction). This division is valid for all the terms of energy and exergy currents, it is very useful for currentology. In energy equation all the quantities, carried by convection are the function of the state, not of the path, that is why it is wrong to call the convection of internal energy U as heat, it is just the thermal energy transfer. The functions of a path, the work and heat are both the **energy transfer conduction** either by impulse (it is work) or by entropy (it is heat) (Yantovski,1989). The first (Oumov) energy conservation equation in divergency form (15) is just energy convection by moving substance. The hot water flow in a heating system is a convection of thermal energy from boiler to user, whereas the conductive transfer of this thermal energy through a wall of home battery is heat.

The third mode of energy and exergy transfer are waves, which can carry impulse, entropy and information either. The most important waves are the electromagnetic ones, predicted by Maxwell and discovered by Herz. These waves (radio, TV, magnetron oven, light, laser) carry the energy current $\partial\mathbf{A}/\partial t\times\mathbf{H}$. For the unit of this current might be used the **solar constant ∅ =1368** W/sq.m, it is the perfectly measured light energy current from the Sun falling on an Earth satellite in space.

Some Examples

In the next figures the numerical examples of **exergy** current densities are measured just in∅:

Natural gas main $\rho VG_\in$ $\approx 3.3.10^6$ ∅

Hot water heating $\rho VU(1-T_o/T)$ $\approx$ 3 000 ∅

Boiler furnace $\rho VU(1-T_o/T)$ $\approx$ 7 000 ∅

Boiler tube wall $\lambda \mathrm{grad}T(1-T_o/T)$ $\approx$ 150 ∅

Electrical generator gap $\partial\mathbf{A}/\partial t\times\mathbf{H} \approx \omega BLH$ $\approx$ 180 000 ∅

High voltage direct current line $\varphi\mathbf{J}_q$ $\approx 7.10^8$ ∅

Wind by 10 m/s $\rho V.V^2/2$ $\approx$0.36 ∅

Averaged solar in Europe ≈0.11 ∅

The mentioned figures vividly show why an energy boiler should be much higher in size than electrical generator. Looking at very low figures for popular renewables (wind and solar) one may understand why the bulk energy supply by solar or wind energy is hardly possible in densely populated, energy intensive, but of rather small land surface countries of Europe: in ordinary fuel-fired power plant the exergy current density is thousands times more, than that of solar or wind. It means, they need much much less land. The question seems to be crucial for the most densely populated and energy intensive part of Europe, the land Nordrhein Westfalen in Germany. V.Smil (1991)systematically investigated the energy current density in energetics and indicated the possible problems of renewables due to very small energy current densities and much land needed.

The figures of another kind illustrate the thermal charges currents. The known, rather old, figures of the attained in practice information flows, measured in bits/s are as follows:

Telegraph 75; Telephone 2500 - 8 000; Television 2.10^7 ; Glass fiber 10^8 .

Let us compare the currents of thermal charges in an optical glass fiber line. Imagine a cable, connecting a warm room (27 C) with a cold one (0 C) posessing a length 27 m. Here the gradT = 1 C/m. The entropy conduction flow is $S^* = J_sF = F(\lambda \text{gradT})/T = 4.5.10^{-11}$ W/K by λ= 1.34 W/m.K, F = 0.0 1 sq.mm, T = 300 K. The negative charge flow (information) $kI^* = 1.38.10^{-23} . 10^8 = 1.38.10^{-15}$ W/K , it is 4 orders of magnitude less, than the positive one. If, however, to use the recent data on the achieved information flows, the figures are different. Modern optical line may carry 320 Gbit/s (Bischop et al.,2001), here $kI^*= 4.4.10^{-12}$ W/K which is very near to mentioned S*. The new technology of MEMS (Micro Electro Mechanical Systems) has demonstrated in July 2000 more than 10 Terabits per second of total switching capacity. Such switches „might support the petabit (quadrillion-bit) systems that are not very far over the horizon". It is evident, that soon the flows of information might exceed the thermal conductivity entropy flows in optical fibers.

Let us compare the information flow from a computer and entropy income due to conversion of electrical power into heat inside it. This ratio might be considered as a thermodynamic computer efficiency:

$$\eta = kI^*/S^* = T_o kI^*/ P = 8.4.10^{-14}$$

Here is assumed I* as for TV, P = 100 W, To = 300 K. For a telefax machine by I* = 9600 bit/s and P = 20 W we have $\eta = 2.10^{-18}$. For a modern note-book computer by P = 1W and information output of 10 Gb/s this efficiency is 4.10^{-11}.

The quite natural question here is this: are the figures with such a small efficiency meaningful, could they make any sense ? The answer is: probably ,yes. The visible way to increase this efficiency was mentioned by Richard Feinman in his lectures on theory of computation: to shift from a crystal to molecular level in the chip structure and to shift to low power consuming transmitters of information. If a handy telephone transmits 8000 bit/s, its power supply should be not less, than $T_o kI^* = 300.1.38.10^{-23}. 8000 = 3.3.10^{-17}$ W.
Contemporary devices consume much more power and the limit is still not within sight. The trend, however, is toward it.

Now let us discuss an energy transfer through a shaft from a turbine to its generator. Almost all the power currents in the world are going through such a shaft. We see the shaft is not standing but rotating. Nevertheless this is an example of conductive energy transfer because there is no motion along the shaft together with energy current. The only motion – rotation, and vectors of forces are perpendicular to the axis. The simple formulation of mechanical work as force times path here is invalid.(McGovern, Yantovski,1996) The answer about direction of mechanical power current $\boldsymbol{\delta}$ gives the second term in eq. (19) and (26): $\boldsymbol{\delta} = \mathbf{V} \bullet \mathbf{P}_{ik}$ which is a scalar product of vector and tensor, written in the compact form. In coordinate form , when $\boldsymbol{\delta}$ has x,y,z components the mentioned scalar product is

$$\delta_x = -V_xP_{xx} - V_yP_{xy} - V_zP_{xz}$$

$$\delta_y = -V_xP_{yx} - V_yP_{yy} - V_zP_{yz} \qquad (28)$$

$$\delta_z = - V_xP_{zx} - V_yP_{zy} - V_zP_{zz}$$

According to the standard rule of indexes of stress components (force applied to a small square) the first index shows the axis to which the square is normal and the second is the force direction. So Pxx is a force along x-axis through a square perpendicular to x axis; it is called normal stress. The same for Y and Z directions. Pxy is the force in Y direction applied to the square perpendicular to X, it means the force vector is in the square, not perpendicular. Such stresses with different indexes are called tangential. Let Z is along shaft and Y,X are orthogonal. As Vz = 0 in (28) disappears the last column. As in the shaft there are no forces through squares perpendicular to X and Y axes whereas exist the shear stresses (tangential) only, in (28) disappear the first and second lines.

So in the rotating shaft are acting only the two terms of bottoming line V_xP_{zx} and V_yP_{zy}_ which describe the current of mechanical energy along the shaft axis δ_z . The distribution of it over the shaft circular cross-section is very nonuniform, energy current density is almost nil in the centre and large at periphery.

Conclusion

Almost all the currents, playing major role in Constructal Theory might be calculated by presented equations of Currentology. The actual demonstration of a particular shape of a system made by mentioned equations is to be done in some future.

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