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A NEW SUBCLASS OF NEGATIVE UNIVALENT FUNCTIONS INVOLVING POLYLOGARITHM FUNCTIONS

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ABSTRACT. In this current work, we introduce and study some properties for the new subclass $\mathcal{N}^{n}_{\beta,\gamma,\delta,b}(\phi(\xi))$ of polylogarithms functions associated with the differential operator $\mathcal{D}^{n}_{\lambda,\delta}f(\xi)$. Also, we have obtained coefficient inequalities, integralmeans of inequalities, extreme points and distortion of the class.

1. INTRODUCTION

Let $\mathcal{A}$ represent the class of functions $\mathfrak{f}(\xi)$ of the form

$$\mathfrak{f}(\xi) = \xi + \sum_{k=2}^{\infty} a_k \xi^k, \tag{1.1}$$

which are analytic in the unit disk $\mathcal{U} = \xi : \quad |\xi| < 1$. If the functions $\mathfrak{f}(\xi)$ are given by (1.1) and $\mathfrak{g}(\xi)$ are given by

$$\mathfrak{g}(\xi) = \xi + \sum_{k=2}^{\infty} b_k \xi^k,$$

then the Hadamard product of $\mathfrak{f}(\xi)$ and $\mathfrak{g}(\xi)$ is defined by

$$(\mathfrak{f} * \mathfrak{g})(\xi) = \xi + \sum_{k=2}^{\infty} a_k b_k \xi^k.$$

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If $\mathfrak{f}(\xi)$ and $\mathfrak{g}(\xi)$ are analytic in $\mathcal{U}$, we state that $\mathfrak{f}(\xi)$ is subordinate to $\mathfrak{g}(\xi)$, i.e. $\mathfrak{f}(\xi) \prec \mathfrak{g}(\xi)$ if a Schwarz function $\mathsf{w}(\xi)$ exists, in whichh $\mathsf{w}(0) = 0$ and $|\mathsf{w}| < 1$ such that $\mathfrak{f}(\xi) = \mathfrak{g}(\mathsf{w}(\xi))$. Moreover, if the function $\mathfrak{g}(\xi)$ is univalent in $\mathcal{U}$, then the above subordination equivalence holds (see [7,8]). $\mathfrak{f}(\xi) \prec \mathfrak{g}(\xi)$ if and only if $\mathfrak{f}(0) = \mathfrak{g}(0)$, and $\mathfrak{f}(\mathcal{U}) \subset \mathfrak{g}(\mathcal{U})$.

For $\mathfrak{f}(\xi) \in \mathcal{A}$, Al-Oboudi [2] initiated the following differential operator:

$$\mathcal{D}_\delta^n \mathfrak{f}(\xi) = \xi + \sum_{k=2}^{\infty}[1 + (k-1)\delta]^n a_k \xi^k, (n \in N_0 = N \cup \{0\}, \delta > 0 : \xi \in \mathcal{U}).$$

For $\mathfrak{f}(\xi) \in \mathcal{A}$, Ruscheweyh [9] initiated the following differential operator:

$$\mathcal{D}^\lambda \mathfrak{f}(\xi) = \frac{\xi}{(1-\xi)^{\lambda+1}} * \mathfrak{f}(\xi) = \xi + \sum_{k=2}^{\infty} \frac{(\lambda+k-1)!}{\lambda!(k-1)!} a_k \xi^k, (\lambda > -1).$$

Let $p(\xi)$ represent the class of form $p(\xi) = 1 + p_1\xi + p_2\xi^2 + \cdots$, which are analytic in $\mathcal{U}$ and satisfy the condition $Re\{p(\xi)\} > 0$.

The Polylogarithms functions $\mathfrak{G}(n, \delta)$ are given by

$$\mathfrak{G}(n, \delta) = \sum_{k=1}^{\infty} \frac{\xi^k}{[1 + (k-1)\delta]^n}.$$

Note that $\mathfrak{G}(-1, 1) = \frac{\xi}{(1-\xi)^2}$ for $k = 1, 2, 3 \ldots$. is Koebe function. For more information regarding polylogarithms of univalent functions see Ponnusamy and Sabapathy [7], K. Al Shaqsi and M. Daraus [4] and Ponnusamy [8]. Now we introduce a function $\mathfrak{G}^\kappa(n, \delta)$ given by

$$\mathfrak{G}(n, \delta) * \mathfrak{G}^\kappa(n, \delta) = \frac{\xi}{(1-\xi)^{\lambda+1}}, \lambda > -1, n \in Z,$$

and obtain the linear operator

$$\mathcal{D}_{\lambda,\delta}^n \mathfrak{f}(\xi) = \mathfrak{G}^\kappa(n, \delta) * \mathfrak{f}(\xi). \tag{1.2}$$

Presently we get the explicit form of the function

$$\mathfrak{G}^\kappa(n, \delta) = \sum_{k=1}^{\infty}[1 + (k-1)\delta]^n \frac{(\lambda+k-1)!}{\lambda!(k-1)!} \xi^k.$$

From the equation (1.2) we define

$$\mathcal{D}_{\lambda,\delta}^n \mathfrak{f}(\xi) = \sum_{k=2}^{\infty}[1 + (k-1)\delta]^n \frac{(\lambda+k-1)!}{\lambda!(k-1)!} a_k \xi^k.$$

Note that $\mathcal{D}^n_{0,1} = \mathcal{D}^n, \mathcal{D}^0_{\lambda,\delta} = \mathcal{D}^\lambda$, which give the Salagean differential operator [10] and Ruscheweyh differential operator [9] respectively. It is obvious that the operator consists of two well known operators. Also note that $\mathcal{D}^0_{0,\delta} = \mathfrak{f}(\xi)$ and $\mathcal{D}^0_{1,\delta} = \mathcal{D}^1_{0,1} = \xi\mathfrak{f}'(\xi)$.

Definition 1.1. *We define $\mathcal{M}^n_{\beta,\gamma,\delta,b}(\phi(\xi))$ be the class of $\mathfrak{f}(\xi) \in \mathcal{A}$ for which*

$$1 + \frac{1}{b}\left(\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right) - \beta\left|\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right| \prec \phi(\xi),$$

where $n, \lambda \in N_0, \beta > 0, \delta > 0, b > 0, \phi \in p; \xi \in \mathcal{U}$.

Definition 1.2. *We define $\phi(\xi) = \frac{1+(1-2\alpha)\xi}{(1-\xi)}$, then $\mathcal{M}^n_{\beta,\gamma,\delta,b}(\phi(\xi)) \equiv \mathcal{M}^n_{\beta,\gamma,\delta,b}(\alpha)$ be the class of $\mathfrak{f}(\xi) \in \mathcal{A}$ for which*

$$1 + \frac{1}{b}\left(\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right) - \beta\left|\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right| > \alpha,$$

where $n, \lambda \in N_0, \beta > 0, \delta > 0, b > 0, \phi \in p, 0 \leq \alpha \leq 1; \xi \in \mathcal{U}$.

Let $\mathcal{T}$ represent the subclass of $\mathcal{A}$ consisting of the functions that can be expressed in the form

$$\mathfrak{f}(\xi) = \xi - \sum_{k=2}^{\infty} a_k \xi^k. \tag{1.3}$$

Now, define the subclass $\mathcal{N}^n_{\beta,\gamma,\delta,b}(\alpha) = \mathcal{M}^n_{\beta,\gamma,\delta,b}(\alpha) \cap \mathcal{T}$. Since $\mathcal{N}^n_{\beta,\gamma,\delta,b}(\alpha) \subset \mathcal{M}^n_{\beta,\gamma,\delta,b}(\alpha)$. Note that $\mathcal{N}^n_{0,\lambda,1,1}\phi(\xi) = \mathcal{K}^n_\lambda\phi(\xi), \mathcal{N}^n_{0,\lambda,1,1}(\alpha) = \mathcal{R}^n_\lambda(\alpha)$ considered by K. AlShaqsi and M. Darus [4], $\mathcal{N}^0_{0,0,1,1}\phi(\xi) = \mathcal{S}^*\phi(\xi)$ considered by Ma and Minda [6], $\mathcal{N}^0_{0,\lambda,1,1}(\alpha) = \mathcal{R}_\lambda(\alpha)$ initiated and considered by Ahuja [1] and $\mathcal{N}^n_{0,0,1,1}(\alpha) = \mathcal{R}_n(\alpha)$ initiated and considered by Kadioglu [3].

2. Main results

Theorem 2.1. *Let $\mathfrak{f}(\xi)$ be defined by* (1.3). *Then $\mathfrak{f} \in \mathcal{A}$ if and only if*

$$\sum_{k=2}^{\infty}(k - kb\beta + b\beta - 1 + b - b\alpha)[1 + (k-1)\delta]^n \mathcal{C}(\lambda)\,|a_k| \leq (1-\alpha)b, \tag{2.1}$$

where $\mathcal{C}(\lambda) = \frac{(k+\lambda-1)!}{\lambda!(k-1)!}, 0 \leq \alpha < 1, n \in N_0 = N \cup \{0\}, \delta > 0, b > 0, \lambda \geq 0; \xi \in \mathcal{U}$.

Proof. Suppose that the inequality (2.1) is true and $|\xi| < 1$. Then it shows that the values of $1 + \frac{1}{b}\left(\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right) - \beta\left|\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right|$ lies in a circle centered at $\mathsf{w} = 1$ whose radius is $(1-\alpha)b$, i.e.,

$$\left|1 + \frac{1}{b}\left(\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right) - \beta\left|\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right| - \alpha + 1\right| < 1,$$

which gives

$$\sum_{k=2}^{\infty}(k - kb\beta + b\beta - 1 + b - b\alpha)[1 + (k-1)\delta]^n \mathcal{C}(\lambda)\,|a_k| \le (1-\alpha)b.$$

Hence $\mathfrak{f}(\xi)$ satisfies the condition (2.1).

Conversely, let us assume that the function $\mathfrak{f}$ is defined by (1.3) in the class $\mathcal{N}^n_{\beta,\gamma,\delta,b}(\alpha)$, then $Re\left(1 + \frac{1}{b}\left(\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right) - \beta\left|\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right|\right) > \alpha$, if we choose the value of ξ on the real axis so that $1 + \frac{1}{b}\left(\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right) - \beta\left|\frac{\xi(\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi))'}{\mathcal{D}^n_{\lambda,\delta}\mathfrak{f}(\xi)} - 1\right|$ is real and let $\xi \to 1^-$ through real values, we obtain the result

$$\sum_{k=2}^{\infty}(k - kb\beta + b\beta - 1 + b - b\alpha)[1 + (k-1)\delta]^n \mathcal{C}(\lambda)\,|a_k| \le (1-\alpha)b.$$

Hence the result is sharp. □

Theorem 2.2. *Let*

$$\mathfrak{f}_1(\xi) = \xi \text{ and } \mathfrak{f}_k(\xi) = \xi - \textstyle\sum_{k=2}^{\infty}\eta_k\frac{(1-\alpha)b}{\psi(\lambda)}\xi^k, k = 2, 3, \ldots,$$

where

$$\psi(\lambda) = \sum_{k=2}^{\infty}(k - kb\beta + b\beta - 1 + b - b\alpha)[1 + (k-1)\delta]^n \mathcal{C}(\lambda).$$

Then $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$ *if and only if it can be expressed in the form* $\mathfrak{f}(\xi) = \sum_{k=1}^{\infty}\eta_k\mathfrak{f}_k(\xi)$, *where* $\eta_k > 0$ *and* $\sum_{k=1}^{\infty}\eta_k = 1$.

Proof. Let

$$\begin{aligned}\mathfrak{f}(\xi) &= \sum_{k=1}^{\infty}\eta_k\mathfrak{f}_k(\xi) = \xi - \sum_{k=2}^{\infty}\eta_k\frac{(1-\alpha)b}{\psi(\lambda)}\xi^k\\ &= \sum_{k=2}^{\infty}\eta_k\frac{(1-\alpha)b}{\psi(\lambda)}(\psi(\lambda) = (1-\alpha)b\sum_{k=1}^{\infty}\eta_k\\ &= (1-\alpha)b(1-\eta_1) < (1-\alpha)b\end{aligned}$$

which shows that $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$.

Conversely, suppose that $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$. Since $|a_k| \leq \frac{(1-\alpha)b}{\psi(\lambda)}, k = 2, 3, ...$ Let $\eta_k \leq \frac{\psi(\lambda)}{(1-\alpha)b}, \eta_1 = 1 - \sum_{k=2}^{\infty} \eta_k$. Then we obtain $\mathfrak{f}(\xi) = \sum_{k=1}^{\infty} \eta_k \mathfrak{f}_k(\xi)$. □

Theorem 2.3. *Let* $\mathfrak{f}(\xi) = \xi - \sum_{k=2}^{\infty} |a_k| \xi^k$, $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$*, then for* $|\xi| = r$*, we have:*

$$r - \frac{(1-\alpha)b}{(b+1-\beta b-\alpha b)(1+\delta)^n(\lambda+1)}r^2 \leq |\mathfrak{f}(\xi)| \leq r + \frac{(1-\alpha)b}{(b+1-\beta b-\alpha b)(1+\delta)^n(\lambda+1)}r^2$$

and

$$1 - \frac{2(1-\alpha)b}{(b+1-\beta b-\alpha b)(1+\delta)^n(\lambda+1)}r \leq |\mathfrak{f}'(\xi)| \leq 1 + \frac{2(1-\alpha)b}{(b+1-\beta b-\alpha b)(1+\delta)^n(\lambda+1)}r.$$

Theorem 2.4. *The class* $\mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$ *is convex.*

Proof. Let the function $\mathfrak{f}_j(\xi) = \xi + \sum_{k=2}^{\infty} a_{k,j}\xi^k, a_{k,j} \geq 0, j = 1, 2$ lies in the class $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$. It is sufficient to prove that $h(\xi) = (\gamma+1)\mathfrak{f}_1(\xi) - \gamma\mathfrak{f}_2(\xi), 0 \leq \xi \leq 1$, the class $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$. Since $h(\xi) = \xi - \sum_{k=2}^{\infty} [(1+\gamma)a_{k,1} - \gamma a_{k,2}] \xi^k$, which implies that:

$$\begin{aligned}\sum_{k=2}^{\infty}&(k - kb\beta + b\beta - 1 + b - b\alpha)[1 + (k-1)\delta]^n \mathcal{C}(\lambda)(1+\gamma)a_{k,1} \\ &+ (k - kb\beta + b\beta - 1 + b - b\alpha)[1 + (k-1)\delta]^n \mathcal{C}(\lambda)\gamma a_{k,2} \\ \leq\ &(1+\gamma)(1-\alpha)b + \gamma(1-\alpha)b \\ \leq\ &(1-\alpha)b\end{aligned}$$

therefore $h \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$. Hence $\mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$ is convex. □

Theorem 2.5. *Let* $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$ *, then* $\mathfrak{f}$ *is close-to-convex of order* $\sigma (0 \leq \sigma < 1)$ *in the disc* $|\xi| < r_1$*, where* $r_1 := \left(\frac{(1-\sigma)[(k-kb\beta+b\beta-1+b-b\alpha)[1+(k-1)\delta]^n C(\lambda)]}{(k)(1-\alpha)b}\right)^{\frac{1}{k-1}}$.

Theorem 2.6. *Let* $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$ *, then* $\mathfrak{f}$ *is starlike of order* $\sigma (0 \leq \sigma < 1)$ *in the disc* $|\xi| < r_2$*, where* $r_2 := inf\left(\frac{(1-\sigma)[(k-kb\beta+b\beta-1+b-b\alpha)[1+(k-1)\delta]^n C(\lambda)]}{(k-\sigma)(1-\alpha)b}\right)^{\frac{1}{k-1}}, (k \geq 2)$.

Theorem 2.7. *Let* $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$ *, then* $\mathfrak{f}$ *is convex of order* $\sigma(0 \leq \sigma < 1)$ *in the disc* $|\xi| < r_3$*, where* $r_3 := inf\left(\frac{(1-\sigma)[(k-kb\beta+b\beta-1+b-b\alpha)[1+(k-1)\delta]^n C(\lambda)]}{k(k-\sigma)(1-\alpha)b}\right)^{\frac{1}{k-1}}, (k \geq 2)$.

Putting $\beta = 0, \delta = 1$ in the Theorem 2.3 which analogue the results of M. Thirucheran, A. Anand and T. Stalin [5] we obtain the corollary:

Corollary 2.1. *Let* $\mathfrak{f}(\xi) = \xi - \sum_{k=2}^{\infty} |a_k|\, \xi^k$ *,* $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$*,then for* $|\xi| = r$ *we have*

$$r - \frac{(1-\alpha)b}{(b+1-\alpha b)(2)^n(\lambda+1)}r^2 \leq |\mathfrak{f}(\xi)| \leq r + \frac{(1-\alpha)b}{(b+1-\alpha b)(2)^n(\lambda+1)}r^2$$

and

$$1 - \frac{2(1-\alpha)b}{(b+1-\alpha b)(2)^n(\lambda+1)}r \leq |\mathfrak{f}'(\xi)| \leq 1 + \frac{2(1-\alpha)b}{(b+1-\alpha b)(2)^n(\lambda+1)}r.$$

Putting $\beta = 0, \delta = 1, b = 1$ in the Theorem 2.3 which analogue the results of K. AlShaqsi and M. Darus [4] we have:

Corollary 2.2. *Let* $\mathfrak{f}(\xi) = \xi - \sum_{k=2}^{\infty} |a_k|\, \xi^k$*,* $\mathfrak{f} \in \mathcal{N}^n_{\beta,\lambda,\delta,b}(\alpha)$*,then for* $|\xi| = r$ *we have*

$$r - \frac{(1-\alpha)}{(2-\alpha)(2)^n(\lambda+1)}r^2 \leq |\mathfrak{f}(\xi)| \leq r + \frac{(1-\alpha)}{(2-\alpha)(2)^n(\lambda+1)}r^2$$

and

$$1 - \frac{2(1-\alpha)}{(2-\alpha)(2)^n(\lambda+1)}r \leq |\mathfrak{f}'(\xi)| \leq 1 + \frac{2(1-\alpha)}{(2-\alpha)(2)^n(\lambda+1)}r.$$

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